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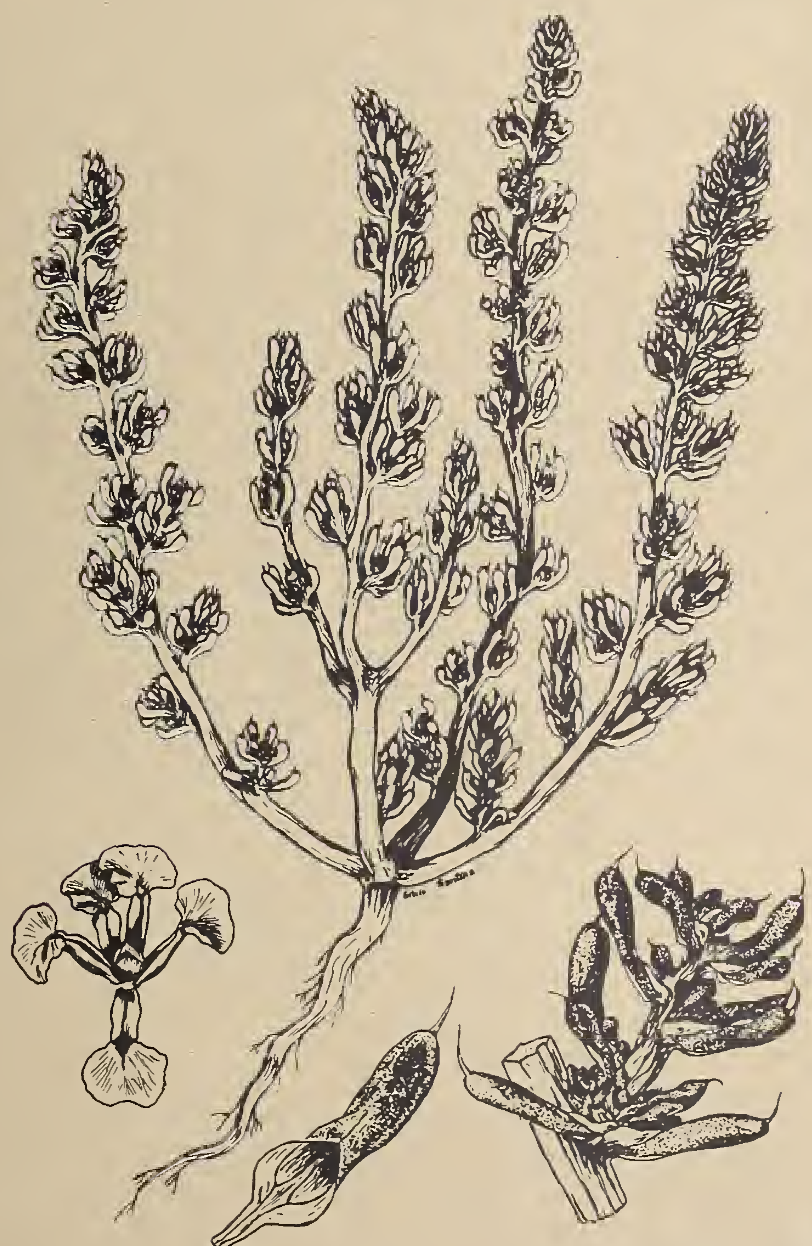
A History of Mid-20th Century Range Conservation in the Intermountain Area



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A History of Mid-20th Century Range Conservation in the Intermountain Area

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Abstract

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Halogeton glomeratus (Bieb.) C.A. Mey., is a fleshy, annual, herbaceous plant that was accidentally introduced into the western U.S. rangelands during the 20th century. Because it is poisonous to sheep, this rather diminutive herb became the center of attention for biological research on rangelands during the 1950s and influenced the structure and direction of post-World War II rangeland research by federal agencies.

This book provides information about the biological, economic, and social ramifications of alien weed invasion of rangelands. Readers may comprise those who depend on rangelands for their livelihood or for a place to live or who are interested in the ecologic health of natural ecosystems. This audience includes livestock producers, land managers, environmentalists, range scientists, and policymakers.

Keywords: desert rangeland, exotic, halogeton, *Halogeton glomeratus* (Bieb.) C.A. Mey., invasive, poisonous plant, range management, western U.S. range management

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Dedication

To Lee M. Burge. Burge was "Mr. Halogeton." More so than any other person, he was instrumental in bringing halogeton to the nation's attention. Burge served the Nevada Department of Agriculture from 1928 to 1972. He was named its director in 1957 and executive director in 1961. He was born in Fresno, California, and graduated from the University of Nevada in 1929. Burge was a strong proponent of the use of herbicides to control the weed. Without Lee Burge, there would not have been a halogeton program.

Contents

Preface

The history of halogeton in the United States provides an opportunity to assess the response of American agricultural research, public land management, and regulatory agencies to the emergence of a major threat to environmental quality and red meat and wool production systems. The most important influence of halogeton was the publicity the weed generated—publicity which alerted a wide spectrum of the American public that not all was right on the western range. Halogeton planted the seeds of awareness for what became a movement about the quality of the environment on publicly owned rangelands.

This, perhaps, was the true importance of halogeton—that it focused the attention of livestock producers, land management agencies, range scientists, and political groups on the problem of degraded rangelands. Methodologies developed and implemented to suppress halogeton also addressed the problem of degraded ranges.

In retrospect, the spread of halogeton had profound influences on the reduction of the desert range sheep industry in much of the Intermountain Area, on revegetation technology, on the knowledge of basic plant and animal physiology, and on establishing the ecological basis for range weed control. The appropriations for research on the suppression of halogeton helped fund the graduate education of numerous scientists who later had distinguished careers in teaching and research.

Attempts to control halogeton on rangelands provided a preview of the controversial use of pesticides in the production of America's food supply. This issue eventually became the most significant controversy in U.S. food production in the 20th century. The use of herbicides to control halogeton became an environmental issue long before pesticide use became an issue in food production. That is because halogeton grew on publicly owned rangelands that were perceived as natural environments as compared to cropland.

Biological control through the introduction of a foreign organism that would miraculously solve the problem was, and generally still is, viewed as the best alternative to pesticides for controlling noxious weeds. However, the most effective answer to the halogeton problem proved to be biological suppression, rather than the much more difficult biological control. Biological suppression consists of returning the ecological balance to plant communities by establishing a perennial species to preempt environmental potential, moisture, and nutrients that otherwise would be available to annual weeds. This technique worked because it treated the basic disease—badly degraded rangelands—rather than the immediate symptom—the halogeton invasion. Halogeton illustrated that not all weeds are adapted to biological control.

Chapter 1. Early History

In the 1930s in the western United States, collecting and preserving plant specimens by pressing and drying were a vocation for natural resource managers and selected taxonomists. Managers had to know the names of the plants in a given area to understand their collective ecologic function—a necessary step in developing management procedures. At that time land managers had no comprehensive flora for the Intermountain Area of western North America. To create one, managers and scientists collected plants from wildlands for herbaria.

Range research in the Intermountain Area was conducted by the Intermountain Forest and Range Experiment Station, of the Forest Service, U.S. Department of Agriculture (USDA), headquartered at Ogden, Utah, and by land-grant universities. The Intermountain station had a rich history dating back to the pioneering efforts of Arthur W. Sampson at the Great Basin station, which was established in 1912 (Keck 1972). The Intermountain area is a vast region bounded by the Rocky Mountains on the east, the Sierra Nevada and the Cascade ranges on the west, deserts to the south, and coniferous forests to the north.

The Intermountain station was the research arm in the Intermountain region of the Forest Service. The region comprised a number of national forests that were established early in the 20th century. These forests constituted a major portion of the higher quality publicly owned rangelands in the Intermountain Area.

Most of the publicly owned rangelands and the poor-condition ranges located at lower elevations were administered by the Grazing Service of the U.S. Department of the Interior. The Grazing Service was established in 1934 by the Taylor Grazing Act after 3 decades of congressional wrangling over control of unappropriated rangelands (Buckman 1935). The service did not have its own research arm, so the Forest Service and university scientists conducted research on its lands.

In the field of range research, Utah State University, in Logan, was one of the world's most highly regarded academic and research institutions under the leadership of Lawrence A. Stoddart and Arthur D. Smith. The Utah State program influenced the careers of many scientists who worked on halogeton. The land-grant colleges in Idaho, Nevada, and Oregon also had range management education and extension programs that encompassed the sagebrush (*Artemisia*) and salt-desert ranges of the Intermountain Area.

The Discovery of Halogeton

One program of the Intermountain station during the 1930s was to develop an understanding of the flora. In June 1934, two station workers, Ben Stahmann and S.S. Hutchings, collected and pressed plant specimens 1 mile northwest of Wells, Nevada. The two took turns putting their names on the specimens to indicate the collector. When it came time to press a fleshy, annual herb that appeared to be a different kind of Russian thistle, it was the turn of Ben Stahmann, a temporary summer employee, to sign the collection slip. This specimen was later discovered to be halogeton (fig. 1). Stahmann's field notes indicated that the new plant was abundant at the collection site in Wells, which is near the geographic center of the Intermountain Area.

Hutchings had a long and distinguished career as a rangeland researcher, especially of salt-desert ranges and the range sheep industry. Stahmann eventually became a veterinarian who practiced in Utah, but in the botanical world his fame was established as the original collector of halogeton in North America (*Salt Lake City Tribune*, September 4, 1951).

In early 1936, the Intermountain Forest and Range Experiment Station plant collection was forwarded to the Washington, D.C., office of the Forest Service (Dayton 1951). In this collection were two of Ben Stahmann's specimens (Forest Service Herbarium Nos. 71,799 and 71,800). These specimens could not be identified at first but eventually proved to be the first specimens of *Halogeton glomeratus* in the United States.

Overgrazing

North of Wells is a major watershed divided among three of the four major hydrologic basins of the Intermountain Area. Thousand Springs Creek flows east to the Bonneville Basin; Salmon Falls Creek flows north to the Snake River of the Columbia River drainage; and tributaries of the Humboldt River flow west into the landlocked Lahontan Basin. During the 1870s, Spanish longhorn cattle from Texas and California were introduced to the sagebrush and grass of the Wells area (Young and Sparks 1985). To the north and east of Wells, Captain John Sparks and his associates developed the largest ranch on the western range during the 1880s. After the hard winter of 1889 and 1890, one supposedly could walk from Wells for 100 miles to the Mary's River fork of the Humboldt and never step off the carcasses of cows that died during the winter.

In 1934, Sparks' ranches passed to the Utah Construction Company, which had ranches composing about 1/32 of the land area of Nevada. Elko County, where

Figure 1. Tobar Siding, near Wells, Nevada, where in 1934 halogeton was first discovered in North America. The roadside vegetation is halogeton.

Wells was located, was often called the most important range livestock county in the United States. By the 1930s, the ranges of Nevada barely resembled those which greeted domestic livestock in the 1870s. Millions of acres of perennial bunchgrasses had been severely overgrazed, while the sagebrush, which cattle did not prefer, had increased in density.

Early in the 20th century, a tremendous range sheep industry developed in northern Nevada. This industry was largely superimposed upon the existing range cattle industry. There was severe competition between cattle and sheep for forage on the vacant public lands that came under the control of the Land Office, U.S. Department of the Interior, but these lands received no supervision as far as grazing management was concerned. Competition was more severe on winter ranges, which were located at low elevations in the valley basins, than on summer ranges. Many of the summer ranges, located in mountainous areas, were under the control of the Forest Service.

Wells was a hub of sheep trails from the summer to winter ranges. When halogeton was discovered in 1934, it was in a largely shattered environment that had been subjected to severe overgrazing. By accident, the discovery corresponded with the beginning of a prolonged period of awakening on relative environmental quality in the Great Basin. Scientists, range managers, wildlife managers, livestock husbandry specialists, and some among the general public became aware that ranges were degraded in relation to their potential. Halogeton became an alarm that sped this awakening because of the high rate at which it would spread unchecked.

First Description of Halogeton

The first published description of halogeton collected in the United States was by Paul Carpenter Standley. A nationally known expert on chenopods (the goosefoot family), Standley (1937) reported that Professor A.O. Garrett had sent to him a chenopodiaceous plant that could not be identified. It was finally identified as *Halogeton sativus* (L.) C.A. Mey., by Paul Aellen, an internationally known expert on the chenopods in Basel, Switzerland. Allen considered the species native to Spain and Algeria. Standley wrote that the plant was first collected by Ben Stahmann in Wells, Nevada, in August 1935, making Stahmann's specimen part of a different collection than the 1934 one in the Forest Service herbarium. Standley suggested that this new species might spread like five-hook bassia [*Bassia hyssopifolia* (Pall.) Kuntze], another chenopod first collected in Nevada.

It was not long before many botanists were visiting Wells in search of new taxa. Noted botanist Percy Train deposited two specimens of halogeton at the University of Nevada herbarium in 1937. He found the specimens while collecting plants along Clarence

King's original 40th parallel survey route in northern Nevada. One specimen, collected on Warm Springs Ranch, Elko County, Nevada, on September 10, 1937, was identified as *Halogeton sativus*. The second, collected July 30 near Jarbidge, in Elko County, was identified as *Halogeton souda* (Loefl.) MacBride.

As part of a Works Projects Administration (WPA) project, leader F.R. Fosberg published in 1940 a contribution toward the flora of Nevada that included halogeton. He identified the material as *H. souda* (Loefl.) MacBride and said it was rapidly spreading in Elko County.

Howard Passey collected halogeton at Bell Canyon, in the Elk Mountains of Nevada in July 1939, and at Wells in September 1938. He sent these specimens to C.V. Morton at the Smithsonian Institution. Morton also received the Train specimens, courtesy of Fosberg.

Morton (1941) reviewed these specimens and the published literature concerning halogeton. Standley seemed unaware that MacBride (1918) made *Halogeton sativus* a synonym of *H. souda*. Morton examined a specimen of *H. souda* with flowers and fruits from Biskra, Algeria, and determined the plants in Nevada did not agree with the Algerian specimen but instead matched specimens of *H. glomeratus* (Bieb.) C.A. Mey.

Origin and Taxonomic History

To find the origin of any new plant, one must first know the history of the botanical classification and hence information on the natural environment of the species. This plant seems to have originated in Asia. The first collection of halogeton by a botanist in the Old World goes back to the golden age of plant exploration and the travels of Christian Friedreich Stephan, an 18th century German botanist employed by the Russian czar. As was typical of the time, Stephan was educated in medicine rather than botany. Herbs were such a part of 18th century medicine that most physicians were knowledgeable in botany by the standards of the time period. Stephan became a professor of chemistry and botany at the Moscow Academy of Science in 1786. He collected halogeton for the herbarium at Moscow but did not formally publish a description of the plant (Dayton 1951).

The first written description of *Halogeton* was published by Marshal von Bieberstein, who described the plant as *Anabasis glomerata* and reported that it grew in the remote deserts of Siberia. Also a German employed by a czar, von Bieberstein accompanied scientific expeditions to Crimea and Persia. He published a report on plant resources of the Caspian Sea area between the Terek and Kur Rivers.

The generic name *Halogeton* was first prepared by Carl Anton Meyer. Meyer accompanied the Russian botanist Karl Friedreich von Ledebour of the Derpat Botanical Garden on a scientific expedition to the Altai Mountains and assisted Ledebour in publishing *Flora Altaica*. The name *Halogeton* was derived from the Greek *hals* (sea or salty) and *geiton* (habitat).

Zappettini (1953) traced the taxonomic treatment of halogeton in various monographs of the Chenopodiaceae published after *Flora Altaica*. Generally, the family had been subdivided based on the arrangement of the embryo, either annular or spiral. Halogeton falls under the subfamily Salsoloideae, which has spirally coiled embryos. Usually three rather similar species of halogeton are described in the literature:

- *H. tibeticus* Bunge., found in the highlands of Tibet.
- *H. glomeratus* (Bieb.) C.A. Mey., found in the salt steppes of south Russia from the Ural and Aral-Caspian region up to the Kirgiz and Songarian Area; also found in the deserts of Tibet.
- *H. sativus* (L.) C.A. Mey., occurs in southern Spain and northern Africa.

Only *H. sativus* has a widely accepted common name. It is known in European literature as barilla (Zappettini 1953). No acceptable common name has been found for *Halogeton*. Dayton (1951) proposed barilla as the common name for this species in the United States, but his attempt failed. Other suggested common names include the following: in Arabic, guraynah; in English, cultivated saltwort; in French, haloget, barilla; in Spanish, barilla fina; in German, zahmes salzkraut; in Turkish, kalyofu.

Very few American range scientists in the 1950s could read Russian scientific botanical literature. An exception was Jack Major, a plant ecologist at the University of California, Davis. Major (1953) offered a brief note on what he could readily find concerning halogeton. Much of his report was based on his translation of material in Komaarov (1936). Major reported the existence of the following four annual species of halogeton:

- *Halogeton arachnoidens* Mog., distributed from the vicinity of Lake Balkash east and southeast through Sinkiang to Mongolia and Tibet.
- *Halogeton sativus*, distributed in Spain and North Africa (Major gave no authority).

- *Halogeton glomeratus* (MB) C.A. Meyer's (Major's authority), distributed from the north shore of the Caspian Sea east through the upper Irtysh River system, in the deserts and the foothills of the mountains eastward from the Caspian Sea to the Pamifs, and into Sinkiang and Mongolia.

- *Halogeton tibeticus* Bge., distributed eastward into Tibet.

Major indicated the Russian common name for *H. glomeratus* might be translated as "congested halogeton."

A translated version of Komaarov's work is now available, and it contains the same information provided by Major. *Flora Europaea* (Tutin 1964) lists only two species of *Halogeton: H. sativus* (L.) Mog. and *H. glomeratus* (Bieb.) C.A. Meyers. The authors doubt that the two species are distinct.

Major suggested the latest Russian floras maintain the three-species distinction (*H. glomeratus, H. arachnoidens*, and *H. tibeticus* (Major, personal communication, 1982).

Through the cooperation of D.V.I. Grubov of the Leningrad Herbarium, Will H. Blackwell of Miami University, Oxford, Ohio, obtained on loan the specimens of halogeton from Russia and photographs of the original specimen (type specimen). This loan enabled the first comparison of the American material and the type specimen. Blackwell suggested that the American material is *Halogeton glomeratus* (Blackwell et al. 1979).

Dayton (1951) noted that Stephan, author of a flora of Moscow, was actually the first to use the epithet *glomeratus*, but Stephan, as previously noted, did not publish the name. Stephan's specimen is the type of *Halogeton glomeratus* but is labeled *Salsola glomerata* in Stephan's handwriting (Blackwell et al. 1979). His epithet *glomeratus* was later validly published by von Bieberstein as *Anabasis glomeratus*. Meyer subsequently transferred Bieberstein's *glomeratus* to *Halogeton*. Blackwell and associates (1979) consider the most complete and accurate author citation of the name to be *Halogeton glomeratus* (Stephan ex Bieberstein) C.A. Meyer.

Meyer wrote in *Flora Altaica* that he collected halogeton on July 11, 1826 in the vicinity of Semipalatinsk. He described the collection site as follows:

"The alkali spots, whose salt content was evident by the plants growing upon them were covered with *Polyonumen velvex (Anabasis glomerata), Atriplex laciniatum, A. cancum, Statice gemlini, Camforesma ruthericum, Lepidium perfoliatum*, and *L. latifolium, Chorispora sibirica, Sisymbrium sophia, Iris halophila*, and *Glycrrhiza glanulifera*" (Blackwell et al. 1979).

Meyer said that halogeton was widely distributed in the western deserts of Songaria, China, to Kirgiz, in Kazakh of the former USSR (Zappettini 1953). *H. glomeratus* is mentioned only once in a detailed study of soils and 313 plant communities of the vast Bet-Pak Dala Desert stretching east from the Aral Sea to the mountains of central Asia (Kubanskaja 1956). Halogeton is mentioned as occurring on the margins of takyrs (playas). Associated species were *Salsola lanata* Pall., *S. kasakorom* Iljim, *S. affims* C.A.M., *S. crassa* M.B., and *S. foliosa* (L.) Schrod. Halogeton was considered fair to poor winter forage for camels, the lowest element in Kubanskaja's system of evaluating forage species.

According to the recent comprehensive treatment of temperate deserts, *H. glomeratus* is fairly widely distributed in Russia's semideserts (Walter and Box 1983). It is most prevalent in central Asia, especially in the Tsaidam Basin, which is intermediate in location and elevation between Tibet and the Mongolian Plateau. It occurs on sandy-gravelly and rubble-covered areas in the foothills, with *Tamarix ramosissima, Myricaria alopecuroides, Ephedra przewalskii, Calligonum zaidamense, Ceratoides papposa*, and *Lepidium perfoliatum*. On associated sandy soils, *Salsola paulsenii* occurs.

Scientists in the late 1930s and the following 2 decades had a hard time communicating the correct scientific name for halogeton. This failure to communicate on an international level was to have a serious negative impact on efforts to develop biological control measures for the weed.

Chapter 2. The Discovery of Toxicity

While its correct taxonomic name was being established, halogeton was doing quite well at Wells. The Nevada Department of Agriculture surveyed the area in 1940 and determined that halogeton was spreading at an alarming rate and becoming a nuisance weed on cultivated lands and adjacent rangelands (Burge 1946). The department proposed an eradication program using known soil sterilants, contact sprays, and hand grubbing. The estimated cost was $10,000. The weed had not yet been identified as a poisonous plant, and the proposal was not funded.

The Nevada Department of Agriculture is a regulatory agency responsible for ensuring the continued functioning of the agricultural industry within the state. Part of this responsibility is to protect the industry and the general public from foreign pests, including weeds, that are accidentally introduced. When a new weed pest is identified in the state and is judged to be potentially harmful to the environment, the first action is to try and eradicate it before it becomes established. If a single plant of a foreign weed is found growing, the department destroys that plant, surveys to see whether other plants are located in the area, and monitors the area to see if additional plants become established. Eradication is the typical response of regulatory agencies.

First Reports of Toxicity

In the fall of 1942, Elko County herder Nick Goicoa lost 160 sheep from a band grazing on the range near Wells. In November 1942, Dr. C.H. Kennedy, district veterinarian for the State Department of Agriculture located at Elko, made a postmortem examination of a ewe from the Goicoa band. According to his report:

> The sheep had been in the vicinity of Weeks Ranch below Wells in Clover Valley for a week or more and were driven across Highway 93 about 4 to 6 miles south of Wells. They reached a gravel pit about 1/4 mile to the east of the highway. A few were noticed acting queer as they bedded for the night. The next morning 160 dead sheep were counted. One was brought to Elko, and I posted it. A yearling ewe, good flesh, one lobe of the lung shown seemed solid. A section of the same is being sent to the lab with some of the weeds that the owner was quite sure was the one that killed the sheep. The stomach showed a lot of this weed, also a few leaves thought to be mahogany. (Kennedy 1942)

Kennedy reported that in previous years sheep losses were found in an area extending about 60 miles south of Wells. He assumed from the symptoms that the deaths in the previous sheep kill were from black greasewood [*Sarcobatus vermiculatus* (Hook.) Torr.].

In November 1943, Kennedy submitted the plant material from the ewe's stomach to C.E. Fleming at the University of Nevada for identification.[1] According to Fleming, the material looked familiar, and he expected no difficulty identifying the species. However, he could not place it in any of the available botanical keys. By searching through the herbarium, he ultimately identified the material as *Halogeton glomeratus*.

Fleming sent Fred Harris to Wells, where, with Nick Goicoa's assistance, he mapped the sheep band's movements before the poisoning (fig. 2). The map included a location where 2 years previously Gordon Griswold lost nearly 200 sheep to poisoning. Fleming searched the literature for information on halogeton but found only a statement that the plant was fair forage for sheep and cattle (Holmgren 1942).

L.M. Burge, who became a prominent individual in the history of halogeton in North America, wrote the following soon after the Goicoa losses:

> In view of the fact that little or no attention had been paid to this plant prior to the Goicoa losses, the present extent of its area is amazing. Why had the plant not been recorded generally in Elko County before? Perhaps one explanation is the succulent nature of the plant, which we know to be a favorite type of plant to the Mormon cricket. These insects will eat succulent plants of this kind into the ground and may have kept seeding at a minimum during the early years of its presence in Elko County. The Mormon cricket was very numerous in the areas now known to be infested with *Halogeton glomeratus*. After the cricket populations had been reduced, it is entirely probable that the plant was allowed to seed and multiply at its normal rate, resulting in the present heavy infestations (Burge 1943).

Burge wrote this paragraph for a manuscript that was eventually published, although the published version did not contain this paragraph.

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[1] Fleming brought the science of range management to Nevada. He authored numerous publications on ranch, livestock, and range management. Perhaps his most famous study concerned the damage produced by concentrated herding of range sheep and by returning them to the same bedding ground each night. He was among the first to publish scientific articles on poisonous plants on the western range.

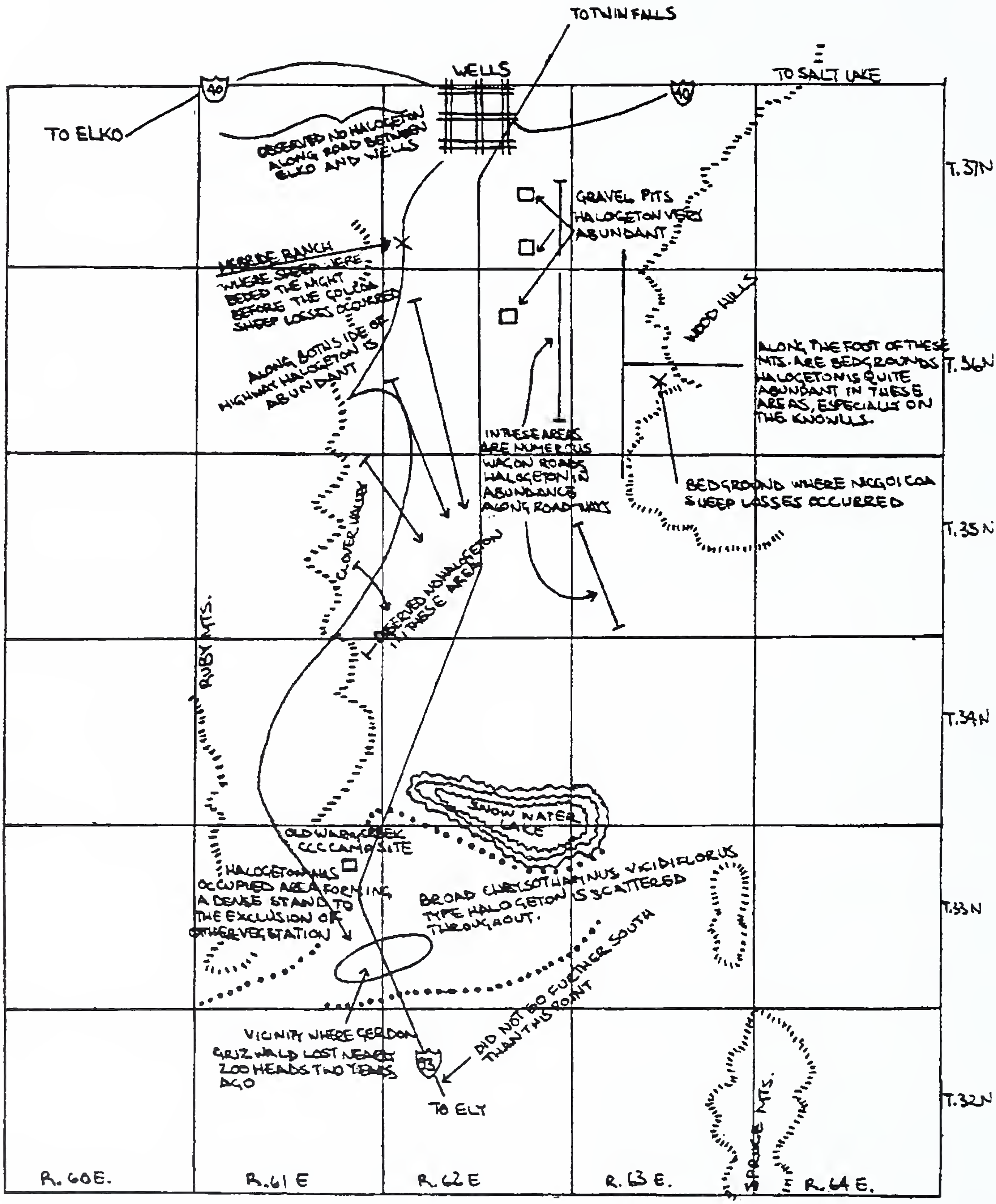

Figure 2. Photocopy of Fred Harris' map (found in C.E. Fleming's records) of the area where Nick Goicoa's sheep were poisoned

The Changing Emphasis of Halogeton Research

It did not take long for the relationship between halogeton and the death of the sheep to be investigated in more detail. Miller (1943) reported that dried samples of halogeton herbage contained total oxalates equivalent to 19 percent anhydrous oxalic acid. Oxalates in water-soluble form were equivalent to 11 percent anhydrous oxalic acid. Miller said that the presence of calcium oxalate crystals could be easily demonstrated by shaking the dry, ground plant material with water. The calcium oxalate collected at the bottom of the liquid, while the plant material floated to the surface.

Late in 1942, research on halogeton at the Agricultural Experiment Station, University of Nevada, was transferred from the area of chemical composition of Nevada range plants and forage crops to the area of poisonous range plants. In FY 1943, the Nevada Agricultural Experiment Station received from the U.S. Department of Agriculture (USDA) $15,000 for three projects. The composition of the research team working on halogeton reflected the nature of the halogeton problem: The project leader was Fleming, a noted expert on the range livestock industry; he was assisted by a chemist, a veterinarian, and an animal scientist.

The Poisonous Range Plants Project had been evaluating the possible harmful effects of prolonged feeding of sheep on shadscale [*Atriplex confertifolia* (Torr. and Frem.) Wats] and Nuttall saltbush [*A. nuttallii* (Jones) Hall and Clem.], in cooperation with the Grazing Service, Department of the Interior. Chemical analysis and feeding trials failed to produce any evidence of toxicity from saltbush but did help establish procedures for future work on halogeton. Feeding trials rapidly established the toxicity of halogeton once suspected. The researchers speculated that halogeton may have caused the losses of hundreds of sheep in northeastern Nevada during the previous decade. These deaths were the reason the saltbush research had been undertaken. Northeastern Nevada was surveyed to try to determine the extent of the halogeton problem.

The purpose of the Poisonous Range Plants Project was to prevent additional animal deaths from halogeton poisoning. The researchers were initially frustrated that there was almost no literature in English on halogeton and that no references in any language reported that halogeton was toxic. During the next 40 years, the search for solutions led researchers to ask many questions involving many fields of science. FY 1944 was the first full year the project involved work on halogeton. During the initial period of research, the project leaders identified the following three research topics—topics still being focused on 5 decades later:

- Oxalate content of the plants varies with the phenology of growth.
- The soils where the plants grow influence the oxalate content.
- Most sheep losses occur under specific conditions of management (for example, herding).

To research these topics, Fleming's group (1) observed grazing sheep on the range, (2) fed sheep in grazing enclosures, (3) performed postmortem examinations of poisoned sheep, (4) analyzed forage and soils for chemical content, and (5) performed feeding trials.

Findings From Toxicity Studies

Fleming's group concluded that the oxalate content of halogeton varied according to the phenological stage of growth. Most livestock losses occurred when the oxalate content was 18 percent or greater. Winter storms leached oxalate from the halogeton, making the plants less dangerous. Sheep losses occurred mainly in the fall and early spring. All sheep losses that the group investigated occurred after sheep had eaten halogeton softened by a storm. The poisoned sheep also ate large quantities of the plant in a relatively short time. The research group also reported that sheep appeared to relish halogeton the first time they ate it. The most disturbing aspect of a 1944 research report were suspicions that cattle were also being poisoned by halogeton.

In 1945, the men involved in the Poisonous Range Plants Project found that halogeton plants could contain as much as 25 percent oxalates and that at least two-thirds of the oxalate content could leach out in a single snowstorm. The sudden leaching of oxalates was thought to be a factor in the erratic occurrence of poisonings and their higher frequency during dry winters.

During the post-World War II years, the range livestock industry enjoyed boom times. In a 1949 article in *Life* magazine (Butterfield 1949), Elko was described as a city where the only thing in short supply was $100 bills. Despite increasing reports of halogeton poisoning, which threatened the flourishing livestock industry, the annual reports from the Poisonous Range Plants Project grew shorter and generally rehashed the same information. Fleming continued to head the project despite his appointment as director of the Nevada Agricultural Experiment Station on July 1, 1946. USDA funds still supported the project, but the same $15,000 amount was split among an increasing number of projects.

Despite time and funding restraints, the Nevada project continued to study halogeton through 1947. Researchers discovered that two forms of oxalate existed, a water-soluble form of sodium acid oxalate and a water-insoluble form consisting of calcium oxalate.

One issue that greatly confused sheep herders and researchers was that sheep did not consistently prefer dry halogeton and often refused to eat it. Sometimes, however, they showed a sudden preference for halogeton and would eat little else, until they consumed enough to cause death. In 1947, researchers speculated that hunger for salt (NaCl) might contribute to this change in preference. Sheep were not salted in the winter. Their salt requirements were obtained from the native forage plants, especially the fruits of shadscale and other saltbush species.

During FY 1949, the Nevada Agricultural Experiment Station studied the blood serum of sheep fed measured amounts of halogeton. Of particular interest were serum calcium levels. Blood calcium levels decreased rapidly when sheep were force-fed toxic levels of halogeton.

The range sheep industry in Nevada was very adversely affected by halogeton, but the College of Agriculture of the University of Nevada devoted little time and money to the problem. Nevada and other Intermountain states had very limited money to spend on agricultural research at the time. This eventually led to a large Federal presence in halogeton research.

Chapter 3. Russian Thistle—A Preview to the Spread of Halogeton

The spread of halogeton was so spectacular during the 1940s and early 1950s that it was never determined whether the plant species was actually spreading or whether it was being recognized at new locations for the first time. It is impossible to judge how abundant and widespread the halogeton infestation was when Ben Stahmann first collected the plant at Wells, Nevada, in 1934. Based on herbarium specimens at the University of Nevada, by 1937 halogeton had spread 90 miles to the northwest and 60 miles to the southwest of Wells.

Fosberg (1940) listed Elko County as the only Nevada location for *Halogeton glomeratus* but said it was spreading rapidly. The annual report of the Nevada Department of Agriculture indicated that surveys of the Wells area in 1941 showed that halogeton was rapidly spreading but speculated that the species could be eradicated.

Lee Burge made the first collection of halogeton outside of Elko County, near the railroad siding of Toy in Churchill County on September 11, 1943 (Burge 1943). That same year the Nevada Department of Agriculture conducted extensive surveys of halogeton, finding large infestations in Elko, Humboldt, and White Pine Counties and minor infestations in Pershing, Lander, Eureka, and Churchill Counties.

Burge described the distribution of halogeton in Nevada this way:

> Generally speaking, the boundaries of infested areas in Nevada extend from a point seven miles west of Toy, on the Victory Highway [Interstate 80], east along this road to Elko where the infestation widens and eventually extends up Mary's River. From this point it extends to Wells and over all of northeastern Nevada to the Idaho and Utah lines thence south along the west slope of the Rockies to McGill in White Pine County, and at intervals west on Lincoln Highway [U.S. 50] to Austin. The area extending from Warm Springs in Ruby Valley, north through Wells to Contact, east to Montello, and south to Cherry Creek is virtually one infestation, all old roads and trails in the area acting as a means of dissemination. (Burge 1943, pp. 4–5)

In order for scientists, land managers, and ranchers to identify halogeton, it was necessary to publish drawings of the plant (fig. 3).

Holmgren, who suggested in 1941 that halogeton was of fair value as forage, later described it as poisonous and suggested, apparently without specimens, that it had already invaded western Utah (Holmgren 1942). Soon after, he announced confirmation that the species infested Box Elder, Tooele, Juab, and Millard Counties (Holmgren 1943).

The Rapid Spread of Russian Thistle

The spread of Russian thistle was a 19th century preview to the spread of halogeton. A review of the events involving the thistle provided evidence of how scientists, agriculturalists, and regulatory agencies would react to invasion by other alien species (Young 1988).

Russian thistle is an annual herbaceous species belonging to the same section of the chenopod family as halogeton. In 1881, the U.S. Secretary of Agriculture reported that a troublesome weed was spreading on the Northern Great Plains. When the first specimen was received from Yankton, South Dakota, USDA botanists had a hard time deciding on a scientific name. Plant taxonomy is a comparative science in which a specimen's morphological characteristics are compared to descriptions in published floras or to pressed herbaria specimens. Obviously, if the specimen was alien to North America and adequate floras for its native habitat were unavailable, the botanists were in trouble. They placed the new weed in the chenopod or goosefoot family and made vague guesses that it might be some form of sea blight similar to species found in brackish habitats along the eastern seaboard. As was the case with *Halogeton* nearly 75 years later, they even disagreed on the common name. The farmers who confronted the new pest on the Great Plains called it "Russian thistle" or "Russian cactus." USDA botanists settled on *Salsola kali* var. *targus*.

The name *Salsola kali* was selected on the basis of plant material collected along the east coast, which was then considered to be native to North America. The botanists did not realize that the Salsola of the east coast was adventive and that its correct name was *Salsola caroliniana* Walter.

Farmers from the Dakotas shipped a steady supply of boxed plants to Washington, D.C., along with stinging complaints. Norm S. French of Grand Rapids, North Dakota, sent a specimen and wrote, "This weed was first seen in this vicinity about four or five years ago [1886–87]. It was observed around the stockyards of the Milwaukee, St. Paul, and Chicago [railroad] at Ellendale and Monango in Dickey County and Edgeley in this county [LaMoure]. Intelligent Russians

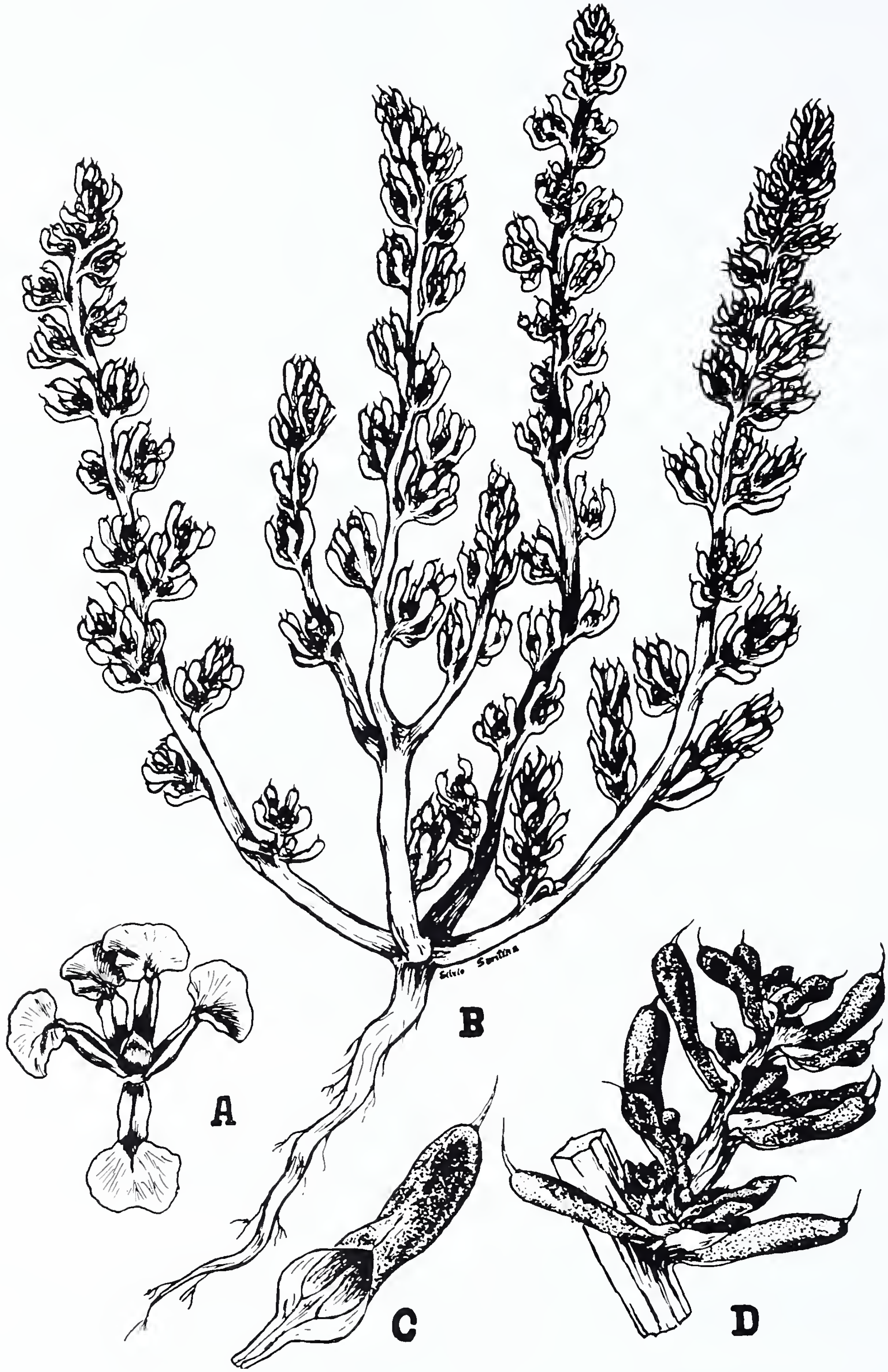

Figure 3. Early example of a botanical drawing of halogeton. *A*, winged seed with bracts (x6); *B*, halogeton plant (1/2 normal size); *C*, leaf, showing curved bristlelike hair on leaf tip (x6); *D*, leaf cluster (x6) (Fenley 1952).

have told me that the weed grows abundantly in southern Russia, in the vicinity of Odessa, where it is locally known as the Tartar thistle, and it is supposed to have been brought to America by Russians in some manner not known" (Dewey 1884, p. 7).

S.W. Narregang, president of the Dakota Irrigation Company, wrote to the Secretary of Agriculture on October 28, 1891:

> I send you here within a fair specimen of the Russian thistle. I would say that we first saw it three years ago. Since that time, it has steadily increased, until at present the greater portion of South Dakota east of the Missouri River is infested with the thistle, particularly the strip of counties extending from Eureka, Campbell southeasterly to Sioux Falls, which is covered thickly with this weed. This obnoxious weed has become so formidable in some portions of the state, notably in Scotland, South Dakota, where the Russians formerly settled, that many farmers are driven from their homes on account of it. A man who was there some time ago states that farmers were leaving their land by the dozens simply because of the evil weed. (Dewey 1884, p. 9)

Warren Opham, who had traveled in the Dakotas as an assistant geologist with the U.S. Geological Survey, offered the comments of a trained scientific observer in a letter to USDA dated September 23, 1891: "During my travels for geologic exploration in North Dakota in 1889, I saw your *Salsola* growing on a railway embankment near Clement, which is a few miles west of Oakes, and again as a weed on a sandy cultivated field on the Souris cotton land, near Towner. The habitat of the plant resembles that of *Amaranthus albus* L. It forms a stiff, prickly, rather compact, green bush 2 to 3 feet in diameter and in hemispherical form" (Dewey 1892, p. 8).

As complaints mounted, the Secretary of Agriculture dispatched assistant botanist Lyster Moxie Dewey to investigate the biological nature of the plant and find a means of eradicating it. Dewey reported that Russian thistle was an annual species, completing its life cycle in a single season. The most objectionable thing about the plant was that its leaves were replaced by strong, sharp spines. Dewey reported that horses running in pastures infested with Russian thistle suffered badly lacerated legs. Some farmers bound their horses legs with leather to protect them.

The most remarkable part of the thistle's life cycle occurred in the fall. With the first frost, the dark green plants turned to crimson or magenta. The color pattern varied among plants. As the November winds blew across the frozen fields, the plants snapped off at the soil surface and, tumbled by the wind, raced across the fenceless, treeless plains, scattering seeds at every turn. The rolling action of the Russian thistle was particularly hazardous during prairie wildfires, when burning plants bounced across fire lines.

Dewey discovered that Russian thistle was first introduced on a farm in Bonhomme County, South Dakota, about 1877. A few seeds of the thistle were mixed with flax seed imported from Europe.

One aspect of the invasion that had ugly social undertones was the widespread belief that the weed was deliberately introduced by Russian Mennonite emigrants in revenge for social injustices received on the agricultural frontier. Dewey went to considerable lengths to dispel this theory.

Russian thistle spread across the plains at about 10 miles per year, with some spectacular jumps as farmers helped its spread by sowing contaminated seed grain. The relentless spread inspired citizen action. E.T. Kearney, a farmer himself, proposed to the North Dakota legislature that the state build a wire fence across the state to hold back the tumbling plants.

The August 14, 1889, *Fargo (North Dakota) Daily Argus* published a report by W.D. Scott on the spread of Russian thistle: "The vanguard of the invader is already north of Sheldon; with the fall winds it will make its appearance in our neighborhood—at Oakes the town is given over to it. LaMoure is gone with it. In the former town, the streets are lined with it. The sidewalks run between hedges of it. The chinks of the sidewalks are fringed with it, the yards and vacant lots are matted with it."

State and regional committees were formed to fight the thistle. E.C. Shortridge, governor of North Dakota, led a drive to petition the federal government for relief. A special tax was passed in North Dakota to help farmers.

In a very short time, Russian thistle had spread from the Northern Great Plains to the rest of western North America. C.V. Piper, of Washington State Agricultural College, recognized it as a threat to the wheat industry in the Palouse region and led a futile one-man crusade to stop it. He enlisted railroad section hands and the president of the Great Northern Railway to find infestations along the railroad right-of-way. Numerous individual plants were destroyed. On July 26, 1897, he received a letter from W.N. Granger, manager of the Yakima Investment Company, telling that a survey had found a 25-acre patch of solid Russian thistle with many outlying individual plants.

California was a major wheat-producing state in the 1890s, and the transcontinental railroad network was a very effective dispersal agent for Russian thistle. Dewey began receiving specimens of Russian thistle collected from southern California as early as 1885. The valleys that bordered the Mojave Desert were infested with scattered plants.

Russian thistle was responsible for some of the first state laws governing weed seeds in grain seed. In most of the plains states, Russian thistle was the subject of one of the first 10 bulletins issued by state agricultural experiment stations. In the 1890s, it was said that in North Dakota losses in wheat production from Russian thistle exceeded the tax revenue of the state's counties.

In its spread across western North America, Russian thistle found a home in the degraded sagebrush rangelands between the Rocky and Sierra-Cascade Mountain ranges. Dewey advised that the weed spread from environmental degradation and poor farming practices. Russian thistle did not establish itself and survive in undisturbed native prairie vegetation. The native forage species on rangelands were being depleted by excessive grazing and the resulting bare ground invited the alien. Overly optimistic farmers had plowed more virgin prairie sod than they could farm, and the vacant plowed fields provided excellent habitat for Russian thistle. The temperate desert environment of the sagebrush ranges was similar to central Asia, where the genus had evolved.

Poor stands of wheat on marginal soils also fostered invasions. From central Mexico to the limits of farming on the Canadian prairies, grain farmers had to live with Russian thistle. And it remains a major challenge, although the development and widespread use of phenoxy herbicides during and after World War II helped reduce the problem.

Three Chenopod Pests

The early history of the Russian thistle in the United States provided an excellent model for what was yet to come. Unfortunately, much of this history had been forgotten when halogeton appeared and much of the painful process of dealing with an unknown exotic plant was therefore to be repeated.

Evidence of the distribution of halogeton began to appear from fields of science other than weed control and range management. It was identified as a host for the beet leafhopper (*Circulifer teuellus*). The insect is a vector for the curly top virus, which had a large economic impact on irrigated crops in the western states. Douglas reported that he had seen halogeton near Deaver, Big Horn County, Wyoming, in August 1943 and west of Deaver in Park County. Douglas and associates (1944) suggested that the ultimate range of halogeton would be somewhere between that of the alien chenopod's five-hook bassia [*Bassia hyssopifolia* (Pallas) Kuntze] and Russian thistle.

Five-hook bassia is native to Europe and Asia. The type specimen from which the species was described was collected near the Caspian Sea. Blake (1922) reported that this species was first collected by Tidestrom near Fallon, Churchill County, Nevada, in 1919. Unknown to Blake, Kearney collected the species in 1917 at Fallon. Blake reported that the plant was well-established before the first collection.

As is the case with many chenopods, *Bassia hyssopifolia* is well adapted to saline/alkaline soils and grows in waste areas outside the potential of crop production. The weed spreads exceedingly fast and currently occupies saline/alkaline environments throughout western North America.

The sepals persist around ripened five-hook bassia fruits, and each bears a hooked spine on its back, an obvious dispersal mechanism. Isolated infestations along the eastern seaboard have tentatively been traced to imported wool.

Despite their similarities, Russian thistle, halogeton, and five-hook bassia have morphological and physiological differences. Russian thistle uses the highly developed self-dispersal system of tumbling. Halogeton plants do not tumble, but the seeds, borne in papery bracts, are highly adapted to short-distance dispersal by wind. Five-hook bassia has hooked fruits for animal-aided dispersal. Broken portions of Russian thistle plants also stick to animal fur. Russian thistle has an extremely wide ecological range and has a life cycle that blends with that of several cereal grain crops, allowing dispersal of seeds in harvested grain. Five-hook bassia is adapted to irrigated agriculture and especially to waste wetland areas associated with irrigation. Halogeton is not a weed of intensive agriculture, either rain fed or irrigated. It is strictly a rangeland and roadside species. As roadside or ruderal species, Russian thistle and halogeton excel. All three species are tolerant to saline/alkaline soil conditions. Halogeton excels in this regard, being perhaps one of the most salt-tolerant herbaceous species.

The amount of historical information available about Russian thistle, in the New World and the Old World, reflects the close involvement of the species with grain production. Russian thistle is a cosmopolitan weed of

eastern Europe and Asia. Halogeton is a species of the remote deserts of central Asia, and this contributes to a relative lack of historical information.

The final difference among the three species is that under specific conditions, halogeton is highly toxic to herbivores, while Russian thistle provides a low-quality forage. Five-hook bassia has also been reported to be toxic to herbivores (Janes, personal communication, 1986).

Chapter 4. Spread of Halogeton Outside the Great Basin

The 1940s and 1950s

The discovery of halogeton in Idaho was dramatic—an entire flock of sheep was poisoned in a short time. In 1945, John Ward of Almo, Idaho, moved a band of ewes to winter range in the Raft River bottoms near Bridge. He gave the following account: "I had lost a few sheep for several years in and around the area west of the Bridge school house. On a day in November, 1945, a band of 1,300 of my sheep were moved into this halogeton area about noon. By 2 or 3 o'clock that afternoon, the sheep were sick and began to die immediately. Of the 1,300 head, 1,000 died that afternoon in that area and the remainder died later on" (Idaho Halogeton and Range Weed Control Association 1950).

About 10 days after Ward's loss, Oscar Jones lost 320 sheep 2 miles south of Almo. Gradually, neighboring herders began to notice that previously unexplained deaths seemed always to happen around halogeton infestations. They discovered that halogeton was distributed in big patches all over the upper end of Raft River Valley (Platt 1952).[1] The loss of John Ward's sheep was a milestone in the halogeton story. Many considered it to be the incident that stirred public interest and brought political interest to the problem.

California became the next state where halogeton was found. Bellue (1949) reported halogeton infestations in eastern Lassen County along the Nevada border. The infestation was largely confined to the Sierra Ammunition Depot at Herlong.

In 1950, isolated infestations were found in San Juan, Emery, and Grand Counties in eastern Utah. Stoddart and associates (1951b) reported that halogeton's presence in these locations indicated the plant had crossed a natural geographic barrier, the Wasatch Mountains, and would be a threat to vast areas of rangeland. These authors also reported that halogeton was growing in Montana.

In 1950, R.S. Zobell and B.W. Silcock, range conservationists with the Bureau of Land Management, surveyed northern Wyoming and southeastern Montana for halogeton. They reported its presence in Park County, Wyoming, north of Ralston in the Big Horn Basin, and in the Clark's Fork and Shoshone River drainages, where it could easily spread into Montana (Zobell and Silcock 1950).

Durell reported in 1951 that halogeton had not yet been found in Colorado. In 1952, however, Domingo Barainoa (who had seen specimens on display at the Western Slope Woolgrower's meeting in Montrose) discovered it near Grand Junction (LaCoste 1953).

The invasion of halogeton east of the Wasatch Mountains triggered fears that the weed would take up selenium from the seleniferous soils of eastern Utah and become toxic from that as well as oxalates. However, Williams and associates (1962) found that, except under unusual circumstances, halogeton is unlikely to contain enough selenium to increase its toxicity.

The 1950 annual report of the Nevada Department of Agriculture reported that halogeton was established in all counties in Nevada and that most of this expansion occurred during the previous 10 years (Nevada State Department of Agriculture 1950).

Stoddart and associates (1951a) added California and Oregon to the list of states definitely infested with halogeton. The Bureau of Land Management performed similar estimates in 1954 and 1957 and found almost a 90-percent increase during those 3 years (table 1). The increase was said to be due to the spread of halogeton and the discovery of new infestations.

Table 1. Estimated number of acres infested with halogeton in 1954 and 1957

	Estimated acres infested	
State	**1954**	**1957**
Oregon	5	75
California	57,875	90,250
Nevada	1,100,000	5,710,000
Idaho	305,000	579,625
Utah	3,687,950	4,872,475
Montana	73,300	32,475
Wyoming	878,700	245,000
Colorado	350	3,850
Total acreage	**6,103,180**	**11,533,750**

Source: U.S. Department of the Interior, Bureau of Land Management (1957).

[1] The area of the Raft River Valley that was infested with halogeton has been extensively seeded with crested wheatgrass. The site where the Ward sheep died became known as the Point Springs Seeding. This area was used for many years for research by the University of Idaho. In 1989, the Point Springs Seeding was renamed the Lee Sharp Research Area in honor of the professor of range science at the University of Idaho.

Blackwell and colleagues (1979) tried to establish a link between pioneer sheep trails (as given by Wentworth 1948) and the spread of halogeton. However, this type of long-distance movement of sheep, which characterized the pioneer period when Intermountain ranges were first stocked with sheep, took place 50 years before the spread of halogeton.

The 1950s to the 1980s

In 1986, R.W. Pemberton, a scientist with USDA's Agricultural Research Service (ARS) conducted a survey and produced a map of the distribution of halogeton. The survey compared counties infested in 1954 and 1980 and was carried out by consulting herbarium curators, weed scientists, extension personnel, and regulatory agencies. Figure 4 is an adaptation of Pemberton's map, showing the distribution of halogeton in 1980 (R.W. Pemberton, personal communication, 1985). From 1954 to 1980, halogeton spread to the following additional counties within the states where it originally appeared: in California to Inyo, Kern, Lassen, Los Angeles, Modoc, Mono, and Nevada Counties; in Colorado to Garfield, Moffat, and Rio Blanco Counties; in Nevada to Clark, Esmeralda, and Harney Counties; in Oregon to Lake County; in Utah to Cache, Davis, Garfield, Kane, Morgan, Rich, Salt Lake, San Juan, San Pete, Salver, Units, and Weber Counties; and in Wyoming to Hot Springs County.

States without infestations in 1954 that were infested by 1980 included Nebraska (Buffalo and Scotts Bluff Counties) and New Mexico (McKinley and San Juan Counties).

There is some confusion in the literature as to the timing of infestation in Lassen County, supposedly the original site of infestation in California (Bellue 1949). Pemberton's map shows that Lassen County (located in the northeast corner of California) was infested in 1954, but he stated that the infestation was new in 1980. Most of the new infestations in California, except for Modoc County in the far northeast, occurred in the Great Basin portions of the state, either in the trans Sierra Nevada or the Mojave Desert portion of southern California. Apparently, as of 1980, halogeton had

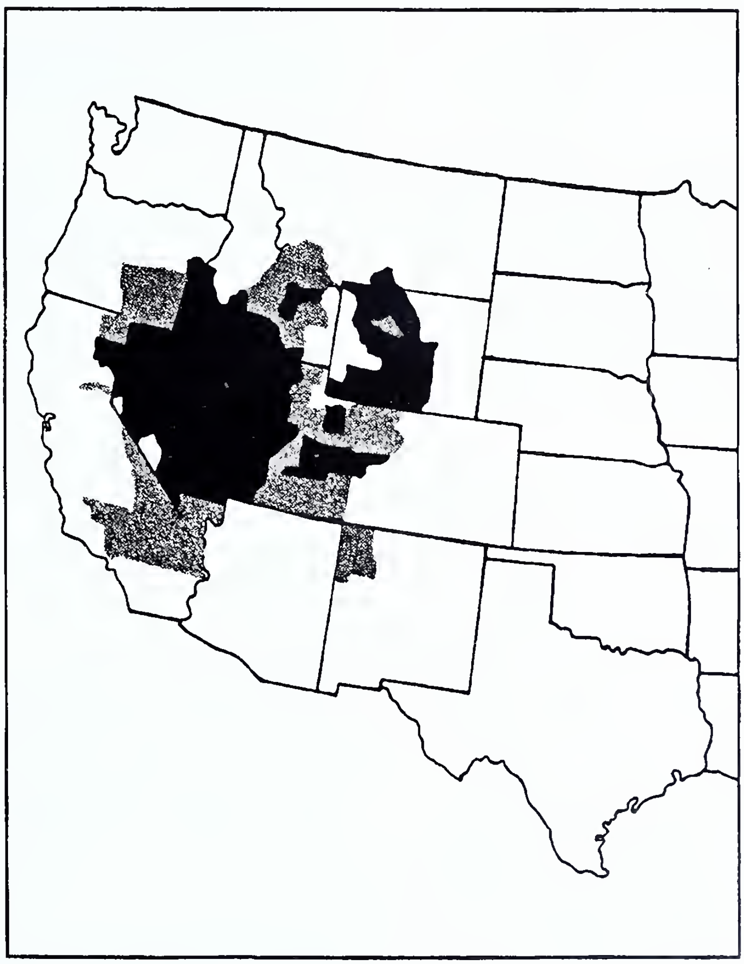

Figure 4. Distribution of halogeton in the western United States. Dark shading, 1954; light shading, 1980 (adapted from Pemberton 1986).

not spread into Baja California, Mexico. The halogeton infestations in California extended south to about 34° latitude.

New infestations in Colorado in 1980 occurred in the northwest, adjacent to infestations in Utah and Wyoming.

In Nevada, halogeton spread to the extreme southern portion of the state in Clark County. This spread represents invasion of Mojave Desert environments, similar to the environment of southern California. Halogeton probably had existed in Esmeralda County since 1954.

The spread of halogeton in Utah from 1954 to 1980 was from west to east across the mountains. Note that Stoddart and associates (1951b) considered San Juan County to be infested in 1951.

In Oregon, halogeton spread to Lake and Malheur Counties in the northwestern extension of the Great Basin. Apparently, halogeton was not yet in the Columbia Basin of Oregon and Washington.

The establishment of halogeton in New Mexico between 1954 and 1980 occurred in the Four Corners area in the northwest.

In Nebraska the weed showed up in two disjunct areas between 1954 and 1980. The Buffalo County infestation was in the eastern half of the state, occurring at near 99° longitude, and represented the easternmost infestation in the United States as of 1980. This longitude is close to that of the original introduction of Russian thistle in South Dakota. The other infestation in 1980 was in Scotts Bluff County, on the western border of the state, over 200 miles away.

In 1990, we asked the states for changes in the distribution of halogeton since Pemberton's study was published. Perhaps the most surprising response came from the New Mexico Department of Agriculture, which did not consider the plant to be established there (Sutherland, personal communication, October 1991). Colorado suggested that Mesa County had been infested for 30 years, and Montrose and Delta Counties probably were also infested (Sullivan, personal communication, October 1991). Nebraska considered Sioux, Scott's Bluff, and Banner Counties to be infested, but not Buffalo County as Pemberton reported (Frilsoe, personal communication, September 1991). In Idaho, the counties of Elmore, Owyhee, Idaho, and Nez Perce were infested in addition to those previously reported (Vega, personal communication, October 1991).

In 1991, halogeton was collected in Arizona in Mojave and Apache Counties (Heuron, personal communication, 1991). The weed was also found at two locations near Flagstaff along Interstate 40 (Hall, personal communication, January 1992).

In 1989, halogeton was discovered at the USDA Agricultural Research Service Range and Livestock Research Station, Miles City, Montana (Haferkamp, personal communication, 1992). The weed was also reported to be located farther north and east of Miles City (Lacey, personal communication, 1992).

Maps from the Montana State Bureau of Land Management documented infestations along the Montana-Wyoming border in Carbon County (south-central Montana), at Fort Keogh in Custer County, in Rosebud and Garfield Counties in north-central Montana, and in Chouteau County south of Harve. The most recent infestation is located near 47° north latitude.

Estimating the Extent of Infestation

Studying the spread of halogeton has not been easy. As mentioned, it has not been determined whether spreading actually occurred or whether observers just became aware of or capable of identifying the species. The spread of halogeton from a single spot infestation was never documented.

Another problem is estimating the degree of infestation. Figures for halogeton infestation have always been reported as gross infested area rather than net infested area. For example, a valley containing several thousand hectares of rangeland was reported as infested, when in fact only roadsides, trails, and saline or alkaline soil slick spots supported halogeton plants.

Frischknecht (1967) thought halogeton had reached its maximum range in 1967. Frischknecht, a range scientist at the Benore Experiment Area in west-central Utah, was known for conducting experiments on environmental conditions that controlled the spread of halogeton.

Halogeton is probably still expanding its range in North America. This probability is interesting because of the relation of day length to seed production of halogeton (see chapter 6) and brings to mind the original suggestion that halogeton would occupy the same range as Russian thistle.

Competition

Halogeton communities are not immune to invasion by other colonizing plant species, demonstrated by the spread of barbwire Russian thistle (*Salsola paulsenii*

Litv.) through the Carson Desert during the 1970s (Young and Evans 1979). Barbwire Russian thistle replaced halogeton in many disturbed areas.

When we started evaluating halogeton in the 1980s, we were all struck by its apparent decline in the Great Basin. We considered several possible interacting reasons for this. The virtual disappearance of the range sheep industry in the western Great Basin and greatly improved range management have vastly improved the condition of salt-desert winter ranges. The introduction of barbwire Russian thistle in the 1960s and the spread of cheatgrass to the margins of the salt deserts have provided strong biological competition for halogeton on many ranges. We also speculated that natural predators adapted to preying on halogeton.

At the end of the 1980s and beginning of the 1990s, 6 years of severe drought occurred in Nevada. In northern Nevada, cheatgrass failed to grow and produce seed for 3 years. Tens of thousands of acres of rangelands were left degraded and virtually bare. Where ranges once covered with cheatgrass had received occasional summer precipitation from thunderstorms, halogeton and barbwire Russian thistle sprung up to fill the ecological void. During the drought, you could drive through areas of halogeton 25 miles long.

Chapter 5. Introduction Into North America

How Halogeton Arrived

There has been a great deal of speculation about how halogeton was introduced from Asia into North America. Erickson and associates (1952) and Blackwell and associates (1979) proposed that it was introduced as a contaminant in crested wheatgrass seed, in wool, or on the wool of Karakul sheep.

The area of central Asia where halogeton is endemic and the northern portion of the Intermountain Area of western North America share equivalent climates (semiarid and arid temperate deserts) and grossly similar vegetation types. In both areas, lower elevations, often with soils that are saline and alkaline, are dominated by members of the chenopod family. Several genera of chenopods are found in both areas [winterfat (*Ceratoides*), kochia (*Kochia*), glasswort (*Salicornia*), sea-blite (*Suaeda*), saltbush (*Atriplex*), and goosefoot (*Chenopodium*)]. Many genera are endemic to only one; for example, Russian thistle (*Salsola*) is prevalent in Asia but not North America, and greasewood (*Sarcobatus*) is prevalent in North America but not in Asia.

Within the large Chenopodiaceae family, six annual chenopods native to central Asia have become widely naturalized in the Intermountain Area. One of these, of course, is halogeton; the other five are as follows:

1. *Chenopodium album* L., lambsquarters

2. *Salsola kali* L.=(*S. australis* R. Br.), Russian thistle

3. *Salsola paulsenii* Litu., barbwire Russian thistle

4. *Bassia hyssopifolia* (Pallas) Volk., five-hook bassia

5. *Kochia scoparia* (L.) Schrad., kochia.

Except for barbwire Russian thistle, these species are cosmopolitan weeds in the former USSR and would have had ample opportunities to enter North America as contaminants in agricultural seed. Barbwire Russian thistle and halogeton have relatively restricted distributions in the former USSR and are not weeds of intensive agriculture. How barbwire Russian thistle was introduced is not known.

During the late 19th and early 20th centuries, the Intermountain Area and central Asia (at least the trans-Caspian area) were relatively remote and sparsely populated and were farmed intensively in areas where irrigation was possible. Livestock production and especially the transhumance culturing of sheep were common in both areas. The Intermountain Area was bisected by transportation routes, both highway and railroad. The trans-Caspian area was bisected by the ancient spice trade routes.

Crested wheatgrass was introduced in North America in 1897 by the South Dakota botanist N.E. Hansen, who worked as a plant explorer for the U.S. Department of Agriculture (Dillman 1946). Hansen obtained his seed from V.S. Bogden at the Valuiki Experiment Station on the Volga River. Bogden may have collected crested wheatgrass from areas where halogeton was endemic, but it is doubtful the weed would have persisted in a nursery located in the black soil belt of Russia. USDA distributed samples of Hansen's crested wheatgrass seed to Alabama, Indiana, Michigan, Colorado, and Washington. The bulk of the seed went to nurseries located on the northern Great Plains, where the grass adapted well.

Prior to World War II, very few crested wheatgrass stands existed in the Great Basin (Young and McKenzie 1982). The first large-scale seeding of crested wheatgrass in Nevada was conducted by J.H. Robertson at Arthur, about 60 miles south of Wells. Numerous small-plot trials existed before that, but they were conducted with domestic seed.

Some ranchers were always experimenting. The August 15, 1905, issue of the *Wells State Herald* reported that A.J. Horrell was experimenting with Russian steppe grasses on the ranch properties located at San Jacinto. San Jacinto was located near modern Jackpot, Nevada, near the Idaho border.

Lyster Dewey was able to pin down where Russian thistle was introduced in South Dakota because the introduction took place in a well-developed farming area rather than on largely vacant rangelands, as was the case with halogeton.

The seeds of many exotic weed species were introduced after they were transported in wool. Large amounts of raw wool were imported into the United States early in the 20th century (Erickson et al. 1952). However, it was not brought to the Intermountain Area. Bringing wool there would have been similar to bringing coal to Newcastle, England.

Erickson and associates (1952) and Burge (1950) suggested that halogeton was adapted for dispersal in wool. Actually, the fruit of halogeton is adapted for dispersal by wind and is therefore not likely to become lodged in wool, making wool dispersal an unlikely means of dissemination.

Halogeton seeds can be ingested by animals, then transported, and defecated as viable seeds. The importation of Karakul sheep is therefore an intriguing theory for the weed's introduction, because of the similarity between the range of these sheep in central Asia and the native distribution of halogeton. However, unless forage or bedding was also imported, the sheep must have had extremely impacted digestive systems to have brought ingested halogeton seed to North America, considering the slow speed of 19th-century transportation. More significant, the sheep came from the Berlin Zoological Garden—well outside the range of halogeton—where they had been kept for several generations.

Bactrian camels were imported from the eastern margins of central Asia to the Great Basin during the mid-19th century (Young 1982), but the chance that they transported halogeton is slight.

Where Humans Go, Halogeton Follows

Weeds like halogeton follow people as they travel around the world. A letter to the editor of the *Reno Gazette* (April 10, 1951) suggested that halogeton was spread from the open cockpits of Russian military planes that flew through the area during an around-the-world flight in the early 1930s. The letter was from the local chapter of the John Birch Society.

Once halogeton was established in the Great Basin, an important mechanism for spreading and introducing the weed was mechanical road-building equipment. The Civilian Conservation Corps (CCC) had numerous road- and trail-building camps scattered in the deserts of northern Nevada. Burge (1944) revealed that virtually every abandoned CCC camp was infested with halogeton (Robertson, personal communication, 1980).

Although Wells is centrally located in the Intermountain Area and was the junction of many of the early 20th-century sheep trails, there is no particular reason to assume it was the introduction site for halogeton. For reasons not readily apparent, Blackwell and associates (1979) postulated that Lassen County, California, was the point of introduction.

There is an unverified report that while attending the 1946 Western Weed Control Conference, George B. Harston of the Wyoming State Department of Agriculture recognized L.M. Burge's halogeton specimens as a species growing in the Powder River area of Wyoming. On returning home, he supposedly verified the existence of halogeton there since at least 1910 (Robertson, personal communication, 1980). This early introduction date was never confirmed by anyone else.

How most of the exotic weeds, so abundant in the Great Basin, were introduced is not precisely known. In one report, an elderly resident remembered seeing cheatgrass on the range in 1905 (U.S. Department of Agriculture 1966). The weed was reportedly plentiful in an area heavily grazed by sheep. It was probably introduced into the western United States as a contaminant of wheat planted in the Pacific Northwest (Mack 1981). The rapid spread of cheatgrass was attributed to the widespread use of steam-powered grain-threshing equipment.

After accidental introduction, herbaceous species of exotic plants are more likely than woody species to become successfully established in the Great Basin. The herbaceous species are either annuals with great seed production and dispersal characteristics or perennials with creeping rootstocks for vegetative propagation. Exceptions are the woody plants tamarisk (*Tamarix pentandra*) and Russian olive (*Elaeagnus angustifolia*), and the semiwoody perennial camelthorn (*Alhagi camelorum*).

Many exotic species adapted to the Great Basin had their origin in central Asia. Many of these plants have shadowed humans and our herds and flocks since the beginning of civilization. The archeologist K.V. Flannery reported that excavations in Iran from some of the oldest agricultural settlements known have yielded carbonized seeds of cheatgrass and Russian thistle along with the bones of domesticated sheep and goats (Flannery 1969).

Chapter 6. Biology of Halogeton

Characteristics of Chenopods

Halogeton, as previously mentioned, is a member of the goosefoot family, Chenopodiaceae. Chenopods are either herbaceous or woody plants, and their leaves are often succulent or scruffy in appearance—the scurfiness coming from a covering of small scales. Chenopodiaceae is a large family with about 100 genera and 1,400 species distributed worldwide. Beets (*Beta*) and spinach (*Spinacia*) are economically important members. Chenopods are often adapted to soils that are saline, alkaline, or both. Because they colonize disturbed environments, many species are considered weeds.

Halogeton is separated from such genera as beets or bassia by its cylindrical, fleshy leaves; beets and bassia have foliaceous (flat, bladelike) leaves. Glasswort (*Salicornia*) and *Allenrolfea* (no common name) do not have the typical broad, flat leaves either; in fact their leaves are completely reduced to scales. *Halogeton* has leaves that resemble little grey-green sausages with a spine or bristly hair at the tip (fig. 5). Kochia and seablite have similar leaves but without the spine on the tip.

The chenopods that most closely resemble *Halogeton* are members of the genus *Salsola*. *Salsola* is a large genus of about 50 species, many of which are native to eastern Europe and Asia. A few herbaceous species have been introduced into North America. Russian thistle and barbwire Russian thistle are widely distributed in the Intermountain West.

Some perennial species of *Salsola* become quite woody, but they have not been introduced into North America from their native Asia. Naturalized *Salsola* species in the Intermountain Area often overlap in distribution with halogeton. Unpaved roads in the Great Basin are frequently lined with alternating patches of Russian thistle, barbwire Russian thistle, and halogeton. Sometimes the three intermingle.

Russian thistle seedlings usually are brighter green than the grey-green seedlings of halogeton. As Russian thistle plants mature, they become intricately branched and rounded in outline. The stems of halogeton are ascending at divergent angles (fig. 5).

Halogeton plants vary greatly in size. Mature plants can be nearly 2 feet high and completely covered with flowers and then seeds. Late-establishing plants may

Figure 5. Halogeton seedling

have only a couple of leaves and, in extreme cases, only a single flower. Plants in dense stands may not attain a height of more than an inch, but they still produce viable seeds in relative abundance.

Mature halogeton plants can be beautiful. The foliage becomes tinged with shades of red, and the mature, silvery sepals that enclose the seeds fall like snow and drift in mini-windrows around the plants. The seeds are enclosed in five winglike bracts and at maturity may cover the plant in an almost-solid mass from the ground to the tip of each branch, so that the fleshy leaves are entirely hidden from view.

There are three distinct color phases of halogeton plants. Young, immature plants contain an enormous amount of moisture and are dull green to blue green, with red stems. At maturity, the plants can be extremely colorful, with red foliage and silver fruits. The plants fade and become straw colored after they freeze and weather.

Halogeton belongs to the group of chenopods with coiled embryos. The embryo consists of a tiny plant with a root (radicle), stem (hypocotyl), and leaves (cotyledons) tightly coiled in a spiral disk. Rauchfuss (1955) presented high-quality microphotographs of sectioned halogeton seeds.

Seed Production, Germination, and Plant Growth

Seed germination can occur over a wide temperature range. Studies performed at the Agricultural Research Service (ARS) Wildland Seed Laboratory, in Reno, evaluated seed germination at 55 different temperature regimes ranging from 0 to 40°C (some at a constant temperature, some alternating) Maximum germination was only 64 percent from the seed source used. However, average germination for the 55 temperature regimes was 55 percent, and some germination occurred at all incubation temperatures. A remarkable 60 percent of the tested temperatures supported optimum germination, which was defined as not significantly lower than the maximum observed ($P = 0.01$)(USDA-ARS, unpublished data, 1980).

Most halogeton seeds germinate early in the spring, but growth is slow and the young plants are not easily recognized until late spring. Some seeds may also germinate during the summer if moisture from unseasonal rain is available. Therefore, plants of various sizes and ages generally are present in halogeton stands. Most seeds are produced late in the summer, but they remain on the plant until late fall or winter. By the middle of the winter most of the seeds have fallen, although even as late as March, a few remain on the plant.

Halogeton does most of its growing in midsummer when most winter annuals such as cheatgrass and native perennials have produced seed, died, and become dormant, or are approaching maturity. Halogeton often uses moisture from summer storms, without serious competition from other plants. Few plants compare with halogeton in its ability to rapidly absorb moisture and store it for growth and seed production (Cook and Stoddart 1953).

One of the first biological observations of halogeton concerned its large numbers of seeds. Holmgren (1943) suggested that prolific seed production was the key to the plant's spread. Burge (1943) reported that mature plants growing under poor conditions could flower and produce seed even though they scarcely reached an inch in height. Large halogeton plants bearing fruit can weigh as much as 5 pounds.

Among the first life history studies of halogeton were those reported by Tisdale and Zappettini (1953). They found that, in southeastern Idaho, halogeton seeds germinated in the early spring while temperatures were quite low, usually in early March. At the time of emergence, daily maximum air temperatures were 35 to 40°F, with minimums of 25° to 30°F. The surface soil was saturated with moisture at the time of germination, while in some cases the soil was still frozen 1 inch below the surface. Seedlings 1/4 inch tall had root systems 1 to 5 inches long. By the end of May, halogeton seedlings were 1 to 5 inches tall and had root systems 8 to 16 inches deep.

Flowering usually starts in late July. The enlarged fruit (utricle) becomes prominent in early September. At this stage, the plants are heavily loaded with masses of fruit. The fruit usually matures by mid-September and is shed by October 1.

Tisdale and Zappettini (1953) reported that 80 percent of the seed germination occurs in the early spring, 16 percent in June, and 2 percent in July and August. Zappettini (1953) and Tisdale and Zappettini (1953) were the first to report that halogeton plants produce both black and brown seeds. Black seeds are more abundant. Each ounce of halogeton seed contains about 55,000 black seeds and 27,000 brown seeds. This research showed that large halogeton plants from spring seedlings produce as many as 25,000 seeds, while plants that germinate in August and reach 2 inches tall produce 200 to 300 seeds. Fruits were distributed from 200 to 500 feet by the wind, depending on the vegetative cover.

Seed Color

In the early 1950s, when halogeton's different seed colors were described, nobody knew that the color

differences could be linked to differences in germination, dormancy, and seed survival. Jansen and Cronin (1954) were among the first to investigate black and brown seed. They collected a large number of halogeton plants from Utah, Idaho, Nevada, Colorado, Wyoming, and Montana in the fall of 1954 to evaluate seed production rate. Jansen determined that 27 brown and 47 black seeds were produced per inch of stem. Large plants could produce 43,500 brown and 74,000 black seeds, or a total of 117,500 per plant.

Trials revealed that black seeds were highly germinable following a brief after-ripening period (Tisdale and Zappettini 1953). "After-ripening" refers to seeds that will not germinate at maturity but become germinable after time passes without additional treatments. Brown seeds failed to germinate.

Cronin (1973) reported that only 24 percent of one population of black seeds germinated 2 weeks after maturity. After 11 weeks of storage, however, germination increased to 60 percent. Moist prechilling at 28°F for 6 weeks followed by 48 hours of incubation at 72°F increased germination to 95 percent. In a strict technical sense, seeds that germinate after prechilling have a prechilling requirement and not an after-ripening requirement.

Williams (1960a) investigated the dimorphic forms of halogeton seeds. He found that black seeds were actually a dark chocolate brown. The five-winged papery sepals, called "bracts," that surrounded the black seeds could be easily removed, leaving the embryo encased in the integuments and ovary wall. The brown seeds were lighter in color and the five bracts were shorter and adhered to the seed. The adherent bracts made the brown seeds appear somewhat larger than the black ones. The embryos of black seeds, however, were slightly larger than those of the brown.

When Williams conducted his studies, there was already some evidence that black seeds germinated readily (Jansen and Cronin 1953). In some cases, black seeds placed on moist filter material absorbed water so rapidly that within an hour the ovary walls ruptured and expelled the embryos. The embryos uncoiled at once, and the resulting seedlings could frequently be planted within 9 or 10 hours.

In contrast, brown seeds have rarely been observed to germinate in the laboratory. Williams found that the brown seeds swelled only slightly in water and that the embryos seemed unable to penetrate the protective ovary walls. He also discovered that embryos excised from brown seeds rarely uncoiled for 48 hours. After they uncoiled, chlorophyll appeared in the cotyledons. The black seed embryos, however, contained chlorophyll before emergence. Despite these differences, the viability of both types of seeds stored was equally very high after storage in the laboratory for 1 year (Williams 1960a).

Williams (1960a) also discovered that black seeds stored most of their resources as sucrose and brown seeds, most of theirs as starch. Brown seeds have a higher total carbohydrate reserve. He suggested that the brown seeds were dormant. At the time Williams was doing this research, in the late 1950s and early 1960s, brown seeds were thought to be immature and therefore nonviable. But Williams showed that the brown seeds were produced first, so they were not likely to be immature. He also showed that the production of brown seeds could be prevented by lengthening the photoperiod. Likewise, no brown seeds were produced by plants growing under shorter photoperiod conditions, such those occurring if the plants germinated and established themselves after August 15. Plants artificially induced to produce only brown seeds formed additional flowers that produced black seed when placed under short-day conditions. The plants died immediately after producing black seeds.

W.C. Robocker was one of the first federal scientists assigned by ARS to study halogeton in Nevada. He organized a cooperative study among scientists to determine the longevity of black and brown seeds buried at four depths. The study lasted 10 years and was conducted in Nevada, Idaho, Utah, and Washington. At all depths, almost 100 percent of the black seeds germinated by the end of the 1st year (Robocker et al. 1969). The ungerminated black seeds were nonviable by the end of the 2nd year. Some of the brown seeds on the soil surface germinated that 1st year, but others on the surface and at deeper depths took up to 6 years to germinate. All of the brown seeds germinated or became nonviable after 6 years.

This study confirmed Williams' research results by showing that the brown seeds are viable but dormant. For a weed to be a highly competitive colonizing species that is capable of invading disturbed sites, it must have seeds that germinate rapidly so the seedlings will not be at a competitive disadvantage. The black seeds fulfill this requirement extremely well. Seeds that germinate extremely rapidly, however, run the risk of seedling loss through sudden changes in the environmental conditions of the seedbed. The brown seeds, with their prolonged dormancy, ensure the persistence of halogeton populations in sites with volatile seedbed conditions.

The discovery that the brown seeds are viable had great practical significance for the halogeton control

programs. The abundance of black seeds, with their nearly instantaneous germination, suggested it was only necessary to control the plant once. The discovery that the brown seeds were, in fact, dormant destroyed the concept that simple control methods would work. The long-term viability of these seeds made eradication of large-scale infestations of halogeton impossible. Biological suppression was the only possible answer to the problem.

Importance of Sodium

In a detailed study of the mineral nutrition of halogeton, Williams (1960b) found that sodium was an essential element. This discovery of an additional element essential to plant growth was very important in plant mineral nutrition. Optimum growth and oxalate content of halogeton occurred when very high concentrations of sodium were present in the nutrient solution or soil. The sodium in halogeton leaves was used primarily to form salts of oxalic acid. Williams also discovered that relatively high concentrations of chlorine were required for the optimum growth of halogeton. His work indicated that an interaction occurs between Na and Cl that promotes greater organic acid metabolism. His basic conclusion was that where the soil is high in sodium chloride, halogeton tends to be exceptionally vigorous and high in soluble oxalates.

A consequence of halogeton's exceptional uptake of sodium and chloride is the residue that remains in the herbage. In the form of oxalates, this residue can prove toxic to herbivores. A more subtle influence of these residues is their effect on germination of plant species in halogeton litter. Eckert and Kinsinger (1960) determined that leachate from halogeton mulch altered the chemical and physical properties of soils from salt desert communities. Sodium from the mulch was found to be influential in increasing the permeability, capillary rise of water, and crusting strength of the soils. Salts moved from the lower soil horizons to the surface, changing the environment. Halogeton appears to be one of the few plants that can tolerate the accumulated salts through all phases of growth (Cronin and Williams 1966).

Studies by Kinsinger and Eckert (1961) showed that halogeton can act as a virtual salt pump, absorbing sodium chloride and leaving the salt as a residue on the soil surface. This residue prevents the germination and establishment of desirable forage species. Smith and Rauchfuss (1958) demonstrated that halogeton leachate influenced the germination of seeds of other species.

Chapter 7. Competition

The earliest reports on halogeton stressed that it was not the dominant species in areas of undisturbed native vegetation. Halogeton was typically found along roadsides and trails and in sheep bed grounds and gravel pits. During World War II, it was found on Army Air Corps facilities used for training pilots and crews at Boise, Idaho, and at Wendover and Tonapah, Nevada. For use as emergency landing fields for training flights, dirt strips were graded as triangles in virtually every valley in northern Nevada. The sides of the triangles were about 1,000 feet long. These air fields provided an ideal habitat for halogeton (Burge 1943).

On the Sierra Army Depot at Herlong, California, and at Tooele Army Depot, Utah, halogeton found a home on the soil mounds used to cover ammunition storage bunkers. For years the Sierra Army Depot fought with the California Department of Food and Agriculture over plans to control the plant on these sites. The Army considered halogeton excellent camouflage. In salt-desert areas, halogeton often occupied saline and alkaline soil slick spots, which no native species could endure.

A second major location for halogeton establishment included areas formerly occupied by native shrubs that were valuable browse. The shrubs included winterfat [*Ceratoides lanata* (Pursh) Howell] (formerly *Eurotia*), green molly (*Kochia americana* Wats.) (sometimes called red sage), and Nuttall saltbush (*Atriplex nuttallii* Wats.), all members of the Chenopodiaceae family. They usually grow in communities that are nearly monospecific, and the browse is highly preferred by domestic sheep and cattle.

Winterfat

Populations of winterfat exhibit considerable ecotypic variability. Usually, a particular form of winterfat prevails within a given area, although two different ecotypes may grow on adjacent, seemingly similar areas (Stevens et al. 1977). Dwarf forms less than 6 inches tall are most often found on the lake plain soils of pluvial lake basins in northern Nevada and Utah. A larger form 5 feet tall occurs in areas of higher precipitation in association with conifer woodlands. Stevens and associates (1977) reported that a dwarf form occurred under the restricted growing season of the Canadian Yukon. Besides growth form, ecotypes of winterfat vary in seed production, size, seedling vigor, and germination characteristics (Workman and West 1967, 1969).

One of the more unusual upright ecotypes of winterfat occurs on Lahontan sands in the Hot Springs Mountains of the Carson Desert in western Nevada. This low mountain range, located in the floor of pluvial Lake Lahontan, is being partially covered by wind-driven sands from the former delta of the Truckee River where it flowed into the pluvial lake. An extreme upright ecotype, to 5 feet tall, grows on northern exposures of steep dunes.

Winterfat survives extreme droughts. It has an extensive fibrous root system, as well as a deep-penetrating tap root. The fibrous roots have been traced 5 feet below the soil surface, and the tap root has been found at a depth of 25 feet (Stevens et al. 1977). In natural stands, 6 weeks after germination, lateral roots have been determined to extend 3 feet and the tap root has been found at a depth of 2 feet. During prolonged droughts, growth is negligible and the plants may appear to be dead. But the woody crowns survive and the buds renew growth with the return of available soil moisture. The centers of old winterfat plants die, often as a result of attacks by big-headed grubs. The separated portions of the crown can become distinct plants.

Winterfat's tolerance to winter grazing is remarkable. In an environment where shrubs dominate the vegetation, such as the temperate deserts of western North America, winterfat was a welcome find for pioneer stockmen (Young and Sparks 1985). The species of sagebrush that characterize this landscape generally are not preferred by domestic livestock. The high preference by cattle for winterfat herbage after a hard frost was a pleasant discovery. Winterfat was, in no small part, responsible for making the range livestock industry possible in the Great Basin.

Overgazing and Foraging

Eckert (1954) concluded that excessive grazing in the late spring and summer appeared to be the major cause of the mortality of winterfat stands and the subsequent invasion by halogeton. In stands where all ages of winterfat were present, halogeton was largely excluded. But on sites without young winterfat, grazing sufficiently weakened the stands to allow halogeton to increase.

Persistent overuse of winterfat—removal of more than 25 percent of the herbage—during the growing season is very detrimental and results in serious depletion of stands (Stevens et al. 1977). During drought years when soil moisture is depleted early in the season, grazing of winterfat during the growing season is extremely harmful.

Eckert (1954) reported that his study areas in Clover and Independence Valleys near Wells, Nevada, and Flanigan, north of Reno, were severely overgrazed,

primarily by range sheep. He suggested that winter foraging by jackrabbits seriously weakened stands. A natural part of the temperate desert ecosystem, jackrabbit populations are cyclic in nature. Periodically, they can become superabundant in a given location and later they virtually disappear from the landscape.

Rangelands of the Great Plains and the Intermountain Area and the southwestern deserts of North America are inhabited by several species of large hares, commonly known as jackrabbits (McAdoo and Young 1980). Hares belong to the family Leporidae, genus *Lepus*. Eleven species have been described from North America, seven known as jackrabbits. The two major species in the continental United States are black-tailed jackrabbits (*Lepus californicus*) and the white-tailed jackrabbit (*L. townsendi*).

Jackrabbits are structurally, behaviorally, and physiologically adapted to arid environments. They can survive without a supply of drinking water, depending primarily on the herbage they consume for their water.

Jackrabbits consume whatever forage is available, but generally one-fourth to one-half of their diet is composed of grasses. Shrubs such as winterfat make up the bulk of their winter diet. Depending on the location and season of study, anywhere from 6 to 31 black-tailed jackrabbits have been reported to consume as much forage as one domestic ewe, and from 55 to 392 can consume as much as one cow (Currie and Goodwin 1966).

There is no question that in specific situations, concentrations of jackrabbits can severely damage plant populations. The winterfat communities near Wells that were weakened by prolonged, excessive grazing were probably very susceptible to damage by jackrabbits. In Clover Valley, near Wells, an attempted agricultural settlement failed in the late 19th century, in part, because of competition from jackrabbits.

The January 1, 1932, edition of the Elko (Nevada) *Free Press* contained the headline "Thousands of Rabbits Attack Hay Stacks in Metropolis District; Tons of Hay Destroyed Each Night." Ranchers attempted to poison the rabbits to reduce losses. The local agricultural extension agent tried to find a market for dressed rabbit carcasses. One rancher offered to supply 1,500 per day.

Crickets

L.M. Burge (1944) suggested that Mormon crickets were also destructive to winterfat stands. Like the jackrabbit population, Mormon cricket populations are cyclic.

Mormon crickets are abundant in the central Great Basin. They were first recorded as an agricultural pest in 1848, when they threatened the crops of Mormon settlers in the Salt Lake City area (Young 1978). They usually hatch from March through June, depending on the soil temperature. Egg beds vary in size from a few hundred square yards to several square miles.

Practically wingless, Mormon crickets walk and hop. When they migrate in huge masses, they appear to glide along on the ground, making the earth seem like it is moving. A cricket band may travel for days in a direction along a relatively narrow thoroughfare. Several bands may follow the same course in succession.

Bands may be as small as under 300 feet wide and 300 feet long. In 1935 in Elko County, a 10-mile front of crickets advanced unrestrained. Another Elko County band piled up against a barrier fence along the highway for 5 days. Pit traps, a cubic yard in volume, filled with crickets in 3 hours.

Mormon crickets feed in several ways as habitat conditions vary. Sometimes they consume only tender shoots, but if the population density is high, they will strip even mature shrubs. They often consume the current year's seed production of native range plants.

One result of Mormon cricket outbreaks near Wells in the 1930s was the late-season growth of halogeton. After the crickets passed through and severely depleted the already overgrazed rangelands, halogeton germinated, established seedlings, and grew to maturity from midsummer rains.

The overuse of the preferred native half-shrubs such as winterfat and the degraded condition of the land played a critical role in efforts to control halogeton. During the period when halogeton was establishing itself, artificial seeding never successfully established winterfat, red molly, and Nuttall saltbush. Exotic plant material adapted to these sites was not available.

Disturbed Rangelands

Ranchers perceived winterfat as the most valuable forage species on winter ranges. As halogeton grew in dense patches on former winterfat sites, many people thought that the invasion was disastrous. Many in the livestock industry believed that halogeton killed the winterfat. In fact, excessive grazing killed the winterfat, and halogeton grew in the ecological void of the disturbed, nearly barren rangeland.

In long-term studies of the Raft River Valley of Idaho, Johnson (1957) concluded that halogeton had replaced other alien annuals in disturbed portions of the valley. The principal species displaced was Russian thistle. One puzzling finding was an apparent cyclic drop in the density of the two native, short-lived bunchgrasses, squirreltail (*Sitanion hystrix*) and Sandberg bluegrass (*Poa sandbergii*). The distribution and density of halogeton in the Raft River Valley varied considerably over the years, depending on the pattern and intensity of moisture events.

In 1937 the Intermountain Forest and Range Experiment Station, in cooperation with USDA's Bureau of Agricultural Economics, other agencies, and the Nevada Agricultural Experiment Station, conducted a range survey in northeastern Nevada. The Soil Conservation Service (USDA) supplied most of the field crews, with the Grazing Service, which was responsible for most of the publicly owned rangelands, supplying two part-time men from a CCC camp.

The range plant communities were mapped in gross types at a scale of 0.5 inch to the mile. The maps included ratings for susceptibility to degradation. Winterfat communities south of Wells, between the Ruby and Tobar railroad sidings, were mapped as slightly susceptible to degradation. This was the area where halogeton would first be collected several years later. The survey found no halogeton and only one type of Russian thistle.

The only range type in the Wells area listed in danger of severe degradation was juniper woodlands in the foothills. We only have the type maps and legends; the field notes and instructions to the field crews are not available. We are left to wonder whether (1) the range condition was not as bad as originally thought, (2) scientific limitations prevented scientists from recognizing how bad the range condition was, (3) the type maps were correct and the condition classes actually meant that the ranges were so bad that they had only a slight chance of further degradation.

During the mid-1950s in Nevada, Robocker (1958) evaluated all major natural rangeland species that grew with halogeton and concluded that halogeton failed to compete with native plant species, especially native shrubs. This failure was thought to be due to halogeton's shallow root system (Rauchfuss 1955).

In a study of salt-desert shrub communities in the Raft River Valley, Johnson (1957) concluded that degraded winterfat and desert molly stands were subject to invasion by halogeton. He suggested that halogeton and desert molly had very similar ecological requirements. Desert shrub communities dominated by shadscale or black greasewood were in better condition and mostly excluded halogeton.

Cook (1961) investigated contrasting soil characteristics in western Utah where the landscape was characterized by big sagebrush (*Artemisia tridentata* Nutt.) and dense patches of halogeton. Vestiges of root crowns indicated that these patches once supported green molly and winterfat. The soils in the patches were saline and alkaline and had a markedly lower rate of water absorption than adjacent soils on the big sagebrush sites. These differences persisted even after the sites were plowed.

In a study in the Red Desert of Wyoming, Miller (1979) determined that most of the native, perennial Chenopodiaceae species had vesicular arbuscular mycorrhiza growing in association with their roots. He suggested that this association was necessary for the species' prolonged survival on harsh salt-desert sites. In contrast, the roots of halogeton have no such mycorrhiza.

The studies by Robocker and by Johnson raised doubt that halogeton could compete with healthy native vegetation cover on rangelands. This leads to the following question: If halogeton had been somehow introduced to the Great Basin before the arrival of Europeans and their domesticated livestock (that is, before overgrazing took place), would it have persisted? There are some instances in which halogeton has proven to be highly adapted in areas that were not overgrazed, such as on saline and alkaline soils in and on the margins of salt deserts. It is doubtful, however, that halogeton would ever have been a landscape-dominating species under pristine conditions.

Chapter 8. Halogeton Poisoning

The first report that halogeton contained potentially lethal levels of oxalates came from Miller (1943). The Poisonous Range Plants Project of the Nevada Agricultural Experiment Station later found that it contained as much as 19 percent oxalates, as anhydrous oxalic acid. This work showed that the amount of halogeton required to kill a sheep was about 6 ounces per 100 pounds of body weight. Cook and Stoddart (1953) determined that 12 ounces of halogeton (containing 8.7 percent soluble oxalates or 1 ounce of soluble oxalates) were required to kill a sheep. This dose was lethal after fasting the sheep for 36 hours and giving the halogeton in a single feeding.

Dye (1956) found that the combined fraction from the leaves, seeds, and sepals (flower bracts) of the halogeton plant contained most of the soluble oxalate (19.53 to 32.81 percent) and that the stem fraction contained relatively small amounts (1.59 to 5.06 percent). Dye (1956) and Cook and Stoddart (1953) confirmed the unpublished findings of the Poisonous Range Plants Project that soluble oxalates in halogeton were highest in the early fall (about 28 percent) and decreased to a minimum of about 5 percent by early spring. The very high oxalate content of the sepals and seeds meant that animals which licked halogeton fruits from wind drifts beneath desert shrubs were in danger of receiving lethal doses.

Dye (1956) conducted proximate analysis of halogeton herbage and determined the succulent annual had crude protein levels comparable to alfalfa. He speculated that if the oxalate content could be lowered a few percentage points, halogeton could become a desirable forage species. Williams' later work (1960b) on sodium and potassium metabolism indicates that a halogeton plant with genetically lowered oxalate content would not be adapted to highly salty soils.

Dr. J.H. Robertson, professor emeritus of range ecology, University of Nevada, stunned the agricultural college staff during the 1950s when he brought halogeton salad to a faculty party. This took place during the height of public concern over the killer weed. Robertson assured fellow faculty members that the succulent green halogeton shoots were no more of an oxalate hazard than the related chenopod spinach. (Robertson ate his salad.)

The leaching of oxalates from halogeton plants during the winter is highly variable (Dye 1959). If winds and rains occur during the early fall, blowing away the sepals and seeds and leaching the herbage, the drop in oxalates is sudden and pronounced. If the winter is dry with few storms, the high oxalate content persists well into winter. Morton and associates (1959a) reported that the loss of oxalate content was affected more by loss of leaves, seeds, and fruiting bracts than by total precipitation.

Cook and Gates (1960) compared the oxalate content of halogeton herbage from different plant communities in the infested deserts of Utah. They found the amount of exchangeable sodium and base exchange capacity differed significantly among communities, but the soluble oxalate content of halogeton was not significantly influenced by the exchangeable sodium content of the soil.

The literature concerning the pathology and nutrition of halogeton is largely the result of research conducted by Lynn F. James and his associates on the arid desert rangelands northwest of the Great Salt Lake. Working first with Wayne Binns and then as director of the Poisonous Plant Laboratory, Agricultural Research Service, USDA, in Logan, James became the world expert on oxalate poisoning. Binns and James (1960) said the acute systemic effects of oxalate poisoning were due to the removal of blood calcium and an upset of the sodium, potassium, and calcium ions incidental to the formation of insoluble calcium oxalate. This condition is reflected clinically by a slight to severe manifestation of hypocalcemia. After ingesting a lethal dosage of soluble oxalate, sheep experience the rapid onset of hypocalcemia, followed by coma and death within 9 to 11 hours.

Ruminants are the only vertebrates with a highly successful method of digesting forage high in cellulose. This is accomplished by stomachs modified to form anaerobic fermentation chambers. Microorganisms housed in the chambers symbiotically break down the cellulose and provide nutrients that the animal can assimilate.

When oxalate is consumed by ruminants, such as sheep, it may be destroyed by the microflora of the rumen, it may be combined with free calcium in the rumen to form insoluble calcium oxalate and excreted in the feces, or it may be absorbed into the blood where it can react with the ion calcium of the body tissue to form calcium oxalate (Shupe and James 1968).

On a worldwide basis, oxalate poisoning of grazing animals is usually associated with plants of the woodsorrel family (Oxalidaceae). This family consists of about 10 genera and over 50 species widely distributed in temperate and tropical regions (Munz and Keck 1968). Oxalate poisoning of sheep was reported from Australia in the 1920s (Bull 1929) and is still considered to be a problem (Dodson 1959).

In North America, oxalate poisoning has been tied to certain members of the chenopod family. The native plant species most commonly associated with oxalate poisoning before halogeton was black greasewood. Greasewood is a North American endemic shrub.

Greasewood Poisoning

Greasewood was suspected of poisoning sheep in Nevada as early as 1916 (Fleming et al. 1928). It jumped in prominence as a poisonous plant in May 1920 when a large band of sheep was poisoned as it was being trailed out of Nevada into Utah. Within 6 to 10 hours after eating the plant, many of the sheep showed distinct signs of poisoning in varying degrees of severity. Eventually most of the band was lost.

C.E. Fleming, of the Nevada Agricultural Experiment Station, began feeding trials with greasewood in 1918. He and his associates demonstrated that greasewood could poison sheep, and isolated the potassium and sodium salts of oxalic acid from the leaves of the plant (Fleming et al. 1928). The presence of these salts in greasewood herbage was previously demonstrated by Marsh (1923).

The Great Basin Environment

Greasewood is usually found growing on saline and alkaline soils on lake plains, from the margins of the playas outward toward the surrounding mountains, until the groundwater table is sufficiently deep that surface water does not reach groundwater level any season of the year (Kearney et al. 1914). A large fraction of the Great Basin consists of lakes, plains, and playas.

The Great Basin was named by John Fremont after he determined there was no drainage from a large portion of the Intermountain Area south of the Snake River basin in southern Idaho and north of the Colorado River system in southern Utah and Nevada (Young and Sparks 1986). Much of Nevada and Utah, along with northeastern California, southeastern Oregon, and tributary valleys into Wyoming, constitute the Great Basin. The basin is not a single drainage system surrounded by a mountain rim but consists of some 190 mountain ranges that generally are oriented in a north and south direction, with valleys interspersed.

During the Pleistocene Epoch, the valleys among the mountain ranges filled with lakes, as the global climate cooled and evaporation lessened (Mifflin and Wheat 1979). The rise of the lakes corresponded with the advance of continental ice sheets and mountain glaciers. Some of the lakes spilled from their basins, and the overflow drained to the eastern and western portions of the Great Basin. The structure of the Great Basin has been likened to a collapsed arch, with the lowest elevations on the western and eastern portions and the higher interior portion consisting of masses of higher mountain ranges.

The lakes that formed during the Pleistocene Epoch are termed "pluvial," referring to wetter times (Russell 1885). On the eastern edge of the Great Basin, pluvial Lake Bonneville formed and reached over 1,000 feet in depth. The lake waters crested during the last rise and spilled into the Snake River-Columbia River system and partially drained. In the west, pluvial Lake Lahontan repeatedly formed and dried and never drained to the ocean.

The pluvial lakes were rich in soluble salts. Once the water evaporated, the salts remained in the surface sediments in the former basins. These basins are characterized in their lowest portions by barren flats of very fine-textured sediments, the surface of which is known by a corruption of the Spanish term "playa." These sediments essentially seal the bottoms of the basins and prevent leaching of the soils.

Occasional flooding and salt accumulations keep the playas nearly free of vegetation. The groundwater table is usually very close to the surface, at least during the winter months. In the various types of dunes that occur near playas, extensive areas of greasewood are found (Young et al. 1986). As soon as seedlings of greasewood become established, fine-textured erosion products from the playa surface begin to accumulate (Young and Evans 1986). This results in the growth of mounds beneath the plants (Flowers 1939). The soils of the mounds are slightly coarser in texture than the playa sediments, allowing for some leaching of soluble salts as the mounds increase in height. The plants develop a two-story root system, with fine roots holding the mound together and providing sites for nutrient exchange and taproots reaching down to the groundwater table.

Greasewood plants have the ability to take up water where the osmotic potential has been greatly lowered by dissolved salts. This is accomplished by allowing soluble salts, which would be toxic to other plants, to pass through cell membranes with the water. The toxic salts are excreted or shunted to various parts of the plant, partially as oxalates. The deciduous leaves and subtending flower parts that constitute the complex fruits (utricles) provide sites for salt deposition within the plant. Greasewood either dominates or shares dominance with a variety of other plants that reach from the playas across the lake plain (Young et al. 1986).

The lake plains merge into the outer margins of alluvial fans (Shantz and Piemeisel 1940). The rise in elevation that accompanies the encroachment of fill into the basin increases the distance between the soil surface and the water table. A point is finally reached where the maximum depth of wetting from the soil surface does not reach the water table. This distance prohibits greasewood roots from reaching the water, and enabling some other form of woody chenopod to dominate the site, usually a species of saltbush (*Atriplex*). Saltbushes underwent explosive speciation as the drying lakes exposed new habitat (Stutz 1978). The variety Bailey greasewood (*S. vermiculatus* var. Baileyi) can continue to persist as the nonphreatophytic dominant of the drier sites. This form is sometimes elevated to species rank (Billings 1945).

Greasewood is a deciduous shrub, as previously mentioned. The initial annual growth consists of highly succulent leaves on soft branches. The juvenile leaves are completely different from the adult leaves. The first leaves look like little fat, green sausages arranged along rapidly growing branches. As the season progresses, the branchlets become hardened spines, and the leaves become leathery. Most cases of sheep poisoning occur in the early spring as the tender growth elongates. The spinescent browse that occurs in the fall is often suspected of injuring cattle by puncturing their internal organs in a way similar to the damage done when they consume small pieces of hay-baling wire. Certain animals highly prefer the browse of greasewood even when quality alternative forage is available. If forced to consume other forage, these animals do not suffer withdrawal symptoms, as would be the case if they were addicted.

The bottoms of the pluvial lake valleys evolved as integral parts of the livestock husbandry system during the 19th century. The arid bottoms of the valleys provided winter ranges when the mountains and foothill sagebrush ranges were covered with snow (Young and Sparks 1985). The wintering sites, which were known as salt-desert ranges, provided excellent browse from nearly monospecific patches of semiwoody chenopods such as winterfat, green molly, or saltbush. Areas of sand provided Indian ricegrass [*Oryzopsis hymenoides* (R. & S.) Ricker.].

During the early 20th century, cattle and sheep continued to use this type of vegetation for winter ranges. The animals often grazed on the ranges in excessive numbers and left late in the spring, so the native shrubs had no opportunity to renew reserves and produce seed before summer drought. Extensive areas of semiherbaceous chenopods were severely depleted or left largely bare.

Many of the excessive grazing problems of the salt-desert winter ranges were caused by the limited number of stock water sources. Russell (1885) mapped the natural springs below the maximum shoreline of pluvial Lake Lahontan. Considering that cattle will graze within a 4-mile radius of water (distance for desert-adapted cattle may be as great as 10 miles), only 10 percent of the salt desert was useable without artificial water sources. Since sheep have a lower water requirement and the ability to satisfy this requirement by licking snow, they could use much more of the salt desert if nature cooperated with a skim of snow.

Despite its oxalate content, greasewood herbage makes an important contribution to the forage resources of the salt-desert ranges. In the fall, the leaves and fruits collect in small windrows under the plants, and cattle and sheep will lick these.

It is worthwhile reviewing the complex moisture relations of black greasewood plants, because many of the same factors relate to halogeton. Groundwater is located at shallow depths in the lower portions of many salt-desert basins, but it is highly charged with dissolved salts. If you were to irrigate a normal garden plant with this groundwater, the salt content of the solution would extract water from the plants to the solution because the solution has the highest concentration of solute. Black greasewood and halogeton solve this problem by letting the salts dissolved in the groundwater enter through cell membranes in the roots into the plants' vascular system.

For common garden species, entry of the salts would mean injury and death because many of the salt ions, such as those in sodium, are highly phytotoxic. Black greasewood and halogeton cope with the toxic ions by metabolically shunting the salts into relatively insoluble oxalates. To prevent excessive buildup of the oxalates, the plants concentrate them in organs that are annually lost in such forms as deciduous leaves or flower bracts. As these lost flower parts or leaves accumulate beneath these salt-tolerant plants, the organic portions gradually decay, leaving the relative insoluble oxalates. These oxalates may break down over time until the salts are again soluble. The gradual buildup of salts in this manner may eventually prove fatal to the plant. Such accumulated calcium oxalates may be the source of calcium carbonate that cycles in desert environments.

Once halogeton moved into the greasewood environment, the range sheep industry was subjected to a second potential source of oxalate poisoning. By the time halogeton was introduced, the ranges were severely degraded, compared with the time the range

sheep industry first started grazing greasewood ranges.

Studies of Poisoned Sheep

Shupe and James (1968) described physiopathologic aspects of halogeton in sheep from observations of animals poisoned experimentally and naturally. The symptoms of acute poisoning were similar to those first reported by Cook and Stoddart (1953). Signs of poisoned sheep include depression, anorexia, slight to moderate bleating, lagging behind the flock, weakness, incoordination, eventual recumbency, frothy blood-tinged nasal discharge, coma, and death. In some sheep, signs of poisoning were observed 2 to 4 hours after the ingestion of excessive amounts of halogeton, while in others symptoms did not show up for a number of hours and lingered for days before the animals died.

In acute halogeton poisoning of sheep, the levels of calcium in the blood decreased (hypocalcemia) from a mean of 9.3 mg to 5.1 mg per 100 ml of plasma (James and Binns 1961). Urea nitrogen in plasma, however, increased. Plasma urea nitrogen levels increased from the time of consumption of halogeton to death.

Van Kampen and James (1969) gave detailed descriptions of the gross pathological changes observed in sheep dying from halogeton poisoning. The nature and severity of observed lesions in the rumen depended on how long it took the poisoned animal to die. One of the most spectacular pathologic changes was observed in the rumen. Edema of the rumen wall was apparently related to damaged ruminal arteries. The damaged wall was thought to contribute to death.

Intially, there was confusion over the influence of low levels of halogeton on the health of sheep. Scientists of the Poisonous Range Plants Project speculated that ewes which consumed small amounts might abort. Fenley (1952) indicated that sheep are affected only after consuming a lethal dose.

James and associates (1968a) launched a study of the influence of sublethal amounts of halogeton on the metabolism of major nutrients in sheep. Digestibility of dry matter was higher with the halogeton diet but digestibility of cellulose was the same. Water intake was higher in lambs receiving halogeton. James and his colleagues (1968b) also determined that sheep fed sublethal levels of halogeton had significantly higher rumen pH throughout the feeding period.

Using the artificial rumen technique, James and associates (1967) studied in vitro oxalate degradation and cellulose fermentation by rumen liquor obtained from a sheep before and after feeding on halogeton. Cellulose fermentation was inhibited when 240, 180, or 120 mg of oxalate was added to 100 ml of fermentation medium that contained rumen liquor inoculum from a sheep that had not been fed halogeton. When 60 mg of oxalate was added, cellulose fermentation was highly variable. When inoculum was obtained from a sheep fed halogeton for 3 days, cellulose fermentation took place but at a slower rate and earlier in the fermentation period. Oxalate was degraded even when cellulose was not fermented. In a sheep fed halogeton, oxalate degradation did not take place until after 4 hours of fermentation, but there was a delay of 8 hours in the sheep that were not fed halogeton. Addition of calcium carbonate, calcium chloride, dicalcium phosphate, bone meal, or magnesium sulfate to the fermentation medium that contained oxalate enhanced the fermentation of cellulose. The data suggest that acute oxalate poisoning may involve impaired cellulose fermentation and rumen dysfunction.

For sheep on desert ranges, adequate water is important in maintaining an adequate intake of feed (Hutchings 1954). In a study of the relationship between halogeton consumption and water intake, James and associates (1970) determined that under natural conditions, a sheep grazing desert range areas and with restricted water intake decreases its feed or changes its diet to include the less salty plants. When water is supplied, the sheep will eat readily. At these times, great numbers of sheep may be poisoned on halogeton. The problem is compounded by the fact that the sheep's rumen is relatively empty and therefore the toxic oxalate is more rapidly absorbed. Sheep with an empty stomach are poisoned on less oxalate than those which have a rumen full of feed (Cook and Stoddart 1953).

Pathological studies described lesions in the organs of sheep fed doses of halogeton that cause immediate death (Van Kampen and James 1969). Transitory edema of the reticulum wall was followed by ruminal changes, which began with edema and ended in acute hemorrhagic rumenitis. Crystalline deposits in the walls of ruminal arterioles resulted in vascular damage that caused massive hemorrhages. A specific pattern for the deposition of oxalate crystals in the kidney was seen. There were microhemorrhages in the medulla oblongata.

Intracellular inactivation of calcium- and magnesium-dependent enzyme systems may be significant in causing the deaths of sheep from halogeton. This hypothesis is substantiated by clinical changes in which flaccid paralysis of skeletal musculature precedes death.

James and Butcher (1972) launched an investigation into the reason why some livestock can consume large

amounts of halogeton without apparent ill effects. The effect of progressively higher levels of oxalate on metabolic processes was examined. Diets containing 0, 4, 5, and 6 percent soluble oxalate in the form of halogeton were fed to sheep for about 100 days. The oxalate caused a slight hypocalcemia, increased serum phosphorus, and decreased serum magnesium. There was no effect, however, on calcium, phosphorus, or magnesium balance. Plasma urea nitrogen decreased and blood alkaline phosphatase, pH, carbon dioxide, and oxygen remained unchanged. As the dietary oxalate increased, daily feed intake decreased, water intake increased, wet feces decreased, and urine excretion increased.

These data indicate that sheep can consume large amounts of halogeton. Diets may contain up to 36 percent halogeton with 16.6 percent soluble oxalate without causing ill effects. The danger to grazing sheep appears to involve conditions leading to acute intoxication and death rather than chronic effects.

Halogeton poisoning becomes a problem when sheep consume the plant in such quantities that rumen microorganisms are overwhelmed and cannot metabolize the oxalate (James et al. 1967). At this point, oxalate is absorbed faster than it can be excreted and intoxication occurs. Halogeton poisoning in sheep grazing the deserts of the western United States thus approaches an all-or-none situation. When grazing halogeton, sheep either live with little or no apparent effect or they die within a relatively short period of time. Some become sick but do not die within the first few days. These are few in number and their eventual fates have not been recorded. However, even in these cases, there is no chronic poisoning in the usual sense.

As mentioned, the amount of halogeton a sheep can eat is related to water consumption, which in turn is related to dry matter consumed, ambient temperature, and salt in the diet. It should then be inferred that halogeton consumption under range conditions could be influenced by modifying these factors. The critical problem seems to be how much water a sheep can drink to accommodate both increased ambient temperature and halogeton consumption (water is especially essential for urinary excretion of the salt in halogeton). Field observations indicate that, in most cases where many sheep die from halogeton poisoning, the temperature was warm or moderating.

The knowledge of physiopathologic changes associated with oxalate poisoning of sheep was refined in a study by Littledike and associates (1975). In addition to the well-known hypocalcemia changes, the authors noted concomitant changes in plasma concentrations of glucose, insulin, arterial oxygen, and arterial pH that would have had drastic metabolic implications. Marked decreases in alimentary motility and cardiovascular changes were also apparent.

The toxic reaction to oxalate ingestion can be summarized as follows:

- Oxalate may be absorbed into the blood stream from the rumen, where it may combine with calcium, resulting in hypocalcemia (James 1968).
- Accumulation of calcium oxalate crystals may damage renal tubules and rumen mucosa, thereby interfering with kidney and rumen function (Van Kampen and James 1969).
- Oxalate may interrupt energy metabolism by interfering with the enzymes succinic and lactic dehydrogenase (James 1968).
- The immediate cause of death may be the disruption of energy metabolism (James 1968).

In an experiment to determine if sheep could adapt to halogeton, Allison and Dawson (1977) studied the rates of oxalate degradation by adapted and nonadapted animals. Successful transitions to a halogeton diet were accompanied by at least a 10-fold increase in the in vitro rate of oxalate metabolism by ruminal microbes. A transitional period of 3 to 4 days appeared to be required to select a microbial population that rapidly degraded oxalate. Oxalate-degrading capacity was negligible in adapted sheep whose ruminal fluid did not contain the microbes. Degradation was inhibited by several antibiotics and by exposure of the incubation mixtures to oxygen. In comments on this manuscript, James commented that adapted sheep could eat 2-1/2 times as much oxalate as nonadapted sheep. Allison and associates (1977) isolated 99 pure bacteria cultures from an oxalate-adapted sheep but none degraded oxalate.

Cattle Poisoning

Most of the animal physiology studies about the effects of halogeton concern sheep. James (1970) reported that cattle grazing on winter ranges with a heavy growth of halogeton became stiff and walked with extreme difficulty after bring driven. Some cattle lay down and stayed there for several days. Field observations suggested that the condition was caused by sublethal halogeton poisoning. James (1972) showed that halogeton is more toxic to cattle than sheep, but because of the free-roaming behavior of cattle, they seldom eat enough to become intoxicated.

Losses of cattle attributed to halogeton poisoning were reported almost as soon as sheep poisoning was noted. Headlines in the November 13, 1948, edition of the

Elko Daily News reported that Drs. R.H. Holbert and C.H. Kennedy of the Nevada Department of Agriculture identified 21 cases of cattle poisoned in the Elko area. Generally, only a single cow or a few cows were reported poisoned at once. The winter of 1961–1962 resulted in relatively high losses of cattle (Bruner and Robertson 1963).

In the fall of 1962, two ranchers in north-central Nevada reported losing 150 cattle in one day. On November 29, 1962, Stanley Ellison lost 120 cattle on the last of three cattle drives that month over the same trail. Twenty thousand sheep trailed through this range prior to the death of the cattle. As late as November 28, sheep had been in the area, but only normal trail losses were reported.

Ellison's first herd of 300 and second herd of 1,000 cattle moved down the 20-mile trail under clear skies. The third herd of 1,100 head was moved on a foggy morning. The vegetation was covered with frost, and a trace of snow was on the ground.

During the week prior to the last drive, cattle had been gathered on a crested wheatgrass field. The first day of the drive the cattle were driven 10 miles to a holding corral where they were fed, watered, and held overnight. It was impossible to ascertain the quantities of water and hay offered. The distance from the holding corral to the next well was about 6 miles, with the first 1.6 miles through an area of light to moderate halogeton infestation. The last 4 miles was through alternating big sagebrush and shadscale with no halogeton present.

Halogeton was present around the well and throughout the remainder of the drive. The cattle were watered in the early afternoon. After beginning the final leg of the drive, cattle began staggering out of the herd less than 1/4 mile from the well. Dead animals were found lying from there to the pasture, where the drive terminated, a distance of about 5 miles.

A loss of 30 young cattle on the same day occurred along a creek in a field of crested wheatgrass. Halogeton occupied the trampled zone along the stream. Rumen samples, chemical analyses, and pathological reports confirmed that the cattle died from halogeton poisoning (Brunner and Robertson 1963). The presence of hoar frost on the halogeton probably contributed to the hazardous conditions.

On a rainy day in mid-December 1979, 680 beef cows and calves were rounded up from a crested wheatgrass pasture in south-central Idaho for routine pregnancy testing and vaccination (Lincoln and Black 1980). At mid-afternoon, after a 6-hour roundup, the cattle were driven 6 miles. The drive followed a desert road with a heavy growth of halogeton. Due to the time required to gather the cattle, many cows were hungry when the drive began, and several cows and calves grazed on the damp halogeton. An attempt was made to move the cattle off the roadside, but this was only partially successful.

After 2 hours on the trail, the first affected cow was observed exhibiting posterior ataxia, initial apprehensiveness followed by belligerence, and increased salivation. Ataxia rapidly progressed until the cow lay down and became comatose. Bloat and cyanosis soon developed, and the cow died within an hour.

Two other cows had similar signs and died. On arrival at the corrals, the cattle were put in a field and fed hay. The next morning, eight cows were found dead and five others (four adults cows and one calf) were moderately bloated and either lying down or ataxic. These five animals were treated intravenously with 0.5 ml/lb calcium-dextrose solution. The adults recovered in 24 to 48 hours but the calf died within 12 hours.

In a grazing study in western Utah, cows wintered on salt-desert ranges infested with halogeton initially consumed only small amounts (Parker and James 1978). At first they preferred the browse of native shrubs and dried herbage of forbs and grasses. During each of three winters during the study period, the cows' preference for halogeton gradually increased from 10 percent of the diet to as much as 60 percent. There were few symptoms of halogeton poisoning even when the cows were stressed by vigorous driving.

These two case studies show that, given the right conditions, halogeton can be a sudden and important factor in cattle management.

Chapter 9. Strategies To Prevent Halogeton Poisoning

Oxalates are the cause of halogeton poisoning. Theoretically, if sufficient calcium were present in an animal's digestive tract when halogeton is consumed, the calcium would unite with the soluble oxalates to form insoluble calcium oxalate before the oxalates are absorbed into the blood stream. Consequently, the oxalates would be carried through the digestive tract in an insoluble form and eliminated, with no harmful effects to the animal. This concept had great popularity with many sheepmen because it seemed to offer a simple answer to the halogeton problem.

Supplementation

Cook and Stoddart (1953) and Hart (1953) demonstrated that, by ingesting calcium oxide, sheep increased their tolerance to halogeton. James and Binns (1961) showed that sheep fed rock phosphate slowly recovered after exhibiting marked clinical symptoms of halogeton poisoning. Sheep that received dicalcium phosphate remained active and alert, with only slight changes in blood calcium. Animals fed monosodium phosphate received no protection from halogeton. The animals receiving bone meal also died. Sheep that received calcium carbonate showed a marked depression in blood calcium but recovered. Sheep receiving calcium gluconate had increased blood calcium and potassium but died anyway. Alfalfa pellets with 5 percent dicalcium phosphate successfully protected sheep trailed through halogeton-infested areas.

Several factors must be considered when studying calcium-containing supplements to prevent halogeton poisoning in sheep: (1) the type of calcium formulation, (2) the amount of available calcium supplied, (3) the time between ingestion of lethal dose and supplementation, (4) how full the animals' rumen is at the time halogeton is eaten, (5) determination of the lethal dose, and (6) adequate simulation of environmental and other influential factors (James and Johnson 1970).

Several calcium-containing minerals are available for feeding. Dicalcium phosphate, calcium carbonate, and calcium chloride prevented death in sheep experimentally fed a lethal dose of halogeton, whereas rock phosphate and bonemeal did not (James and Johnson 1970). For the calcium to be effective, it must be in solution in sufficient amounts to combine with ionic oxalate. The differences in the effectiveness might be due largely to differences in solubility. Calcium chloride is the most effective compound and also the most soluble in water.

It seems that the amount of calcium required to prevent halogeton poisoning is that which decreases the level of ionic oxalate in the rumen to less than a lethal level. Achieving this reduction does not require enough calcium to combine with all of the oxalate, as was the case when dicalcium phosphate was fed (James and Johnson 1970).

The amount of dicalcium phosphate necessary to prevent death approaches 4 ounces per day in an average-size sheep experimentally poisoned with halogeton. The problem is to supply adequate amounts of calcium and maintain a palatable supplement. And, even if a palatable supplement were devised, some sheep might consume more than enough for protection and others not enough (James and Johnson 1970).

Livestock Management

As soon as halogeton was recognized as poisonous, the Poisonous Range Plants Project of the Nevada Agricultural Experiment Station accumulated information on range sheep management procedures that either contributed to death or helped to prevent it. It seemed clear that losses could be expected when hungry sheep were suddenly trailed into halogeton patches.

Summarizing management techniques to limit losses, John L. O'Hara, director, Division of Animal Industry, Nevada Department of Agriculture, cautioned against starving the sheep during trailing operations (Nevada Department of Agriculture files, no date). He noted that deprived appetites caused by phosphorus deficiency resulted in excess halogeton consumption, advice that was never verified by experiments. He described the most likely locales for halogeton—along roads, trails, and other points of animal concentrations, such as bed grounds, where the native vegetation had been destroyed.

One unique condition that contributed to halogeton poisoning was hoarfrost. Known in Nevada by the Shoshone-Paiute name "pogonip" or white death, hoarfrost occurs on desert ranges when fog forms in the Great Basin during clear, calm, bitter-cold conditions (figure 6). Sheep wintered on the desert ranges often depend on snow for moisture. They will lick the ice crystals from plants for moisture and then eat the plants. When the plants are halogeton, poisoning can occur.

Early publications on halogeton recommended livestock management practices plus range seeding to improve forage quantity and quality (Vanter 1951, Fenley 1952, Erickson et al. 1952, Cook and Stoddart

Figure 6. Big sagebrush covered with hoarfrost. Halogeton covered with hoarfrost created a dangerous situation on infested ranges. Sheep lick the frost crystals on the plants and ingest lethal amounts of oxalate.

1953, Bohmont et al. 1955). Researchers specializing in halogeton poisoning, such as Binns and Cronin (1972) did a good job of getting factual information to ranchers and interested professionals such as veterinarians.

Cronin and Williams (1966) believed the relatively lower occurrence of halogeton poisoning in Wyoming than in Utah was a function of a higher level of livestock management in Wyoming. The levels of oxalate in halogeton were shown to be similar in both states.

James and Cronin (1974) summarized eleven management points for minimizing range sheep losses:

1. Avoid overgrazing that creates habitats for halogeton.
2. Develop a grazing management program that allows ranges to improve.
3. Reduce grazing pressure during periods of drought.
4. Avoid late spring grazing that injures native perennials.
5. Supply adequate water, even if it must be hauled.
6. Watch the livestock and know what they are grazing.
7. Allow time for rumen microorganisms to adapt to oxalates.
8. Introduce animals to halogeton-infested areas gradually.
9. Do not unload animals from trucks into halogeton patches unless supplemental feed and water are available.
10. Never allow hungry animals to graze in large, dense patches of halogeton.
11. Do not trail thirsty animals into watering places surrounded by halogeton without food supplementation.

Ralphs and Sharp (1988) recommended management procedures for reducing the risk of livestock losses from poisonous plants. Many of these were published more than 70 years earlier in USDA bulletins (for example, see Marsh et al. 1923). Inexperienced, often untrained herders, who emigrated to the Great Basin from countries with vastly different environments, have been a major contributor to livestock poisoning, especially halogeton poisoning of sheep.

Chapter 10. Control by Nonbiological Means

The initial reaction of almost everyone in the range livestock industry and the administration of public lands to the news about halogeton was to control and eradicate it. Although weed control has existed as long as agriculture has, not everyone was aware of the basic biological and physical principles governing removal of a plant species from a community of plants. The vastness of the sagebrush and salt-desert rangelands defeated the possibility of hand weeding any but the smallest spot infestations. The scale of infestation, coupled with rocks, brush, and irregular topography, also defeated most mechanical treatments.

Herbicides

A relatively new form of weed control using herbicides was coming into vogue in the 1940s (Robbins et al. 1952). Not many herbicides were available. Various types of petroleum distillates and extractions were phytotoxic, and compounds of highly phytotoxic-specific elements such as boron were used sparingly in weed control. The need to control halogeton happened to coincide with the development of plant growth regulators used as herbicides. The first of these new herbicides was 2,4-D [(2,4-dichlorophenoxy) acetic acid].

The secret discovery of 2,4-D during World War II initiated a revolution in chemical weed control. Before the war, the market for herbicides was estimated at $1.5 million to $2.0 million annually. Within two decades following the war, herbicides constituted more than a quarter of a billion dollar industry in the United States (Young et al. 1985).

Plant growth regulators were discovered during the 1930s. P.W. Zimmerman and F. Wilcoxen of the Boyce Thompson Institute produced and tested 2,4-D as a plant growth regulator in 1942, although the actual chemical had been synthesized by R. Pokeray in 1941 (Peterson 1967). E.J. Kraus, head of the botany department of the University of Chicago, conceived of the idea of using massive doses of growth regulators as chemical weed killers. He communicated this idea to John W. Mitchell and Charles L. Hammer, two of his former students, who were working as plant physiologists at USDA in Beltsville, Maryland. Because of the war, this work was not publicized.

During World War II, considerable research was conducted on biological warfare, especially at Camp Detrick, Maryland. Among the biological agents was 2,4-D. Mitchell, Hammer, and P.C. Marsh (another Beltsville colleague) participated in these experiments, but were sworn to secrecy about the chemical warfare aspects of 2,4-D. It was proposed that chemicals could be used to defoliate tropical islands held by the Japanese.

In June 1944, Mitchell and Hammer made the first public suggestion for using 2,4-D as an herbicide (Mitchell and Hammer 1944). In August, Hammer and Tukey (1944) reported that field bindweed (*Convolvulus arvensis* L.) plants sprayed with 2,4-D died within 10 days.

It did not take long for 2,4-D to be tested by range researchers. In 1947 and 1948, landowners in the fringed sagebrush (*Artemisia frigida*) belt of western Oklahoma and the Texas Panhandle sprayed about 100,000 acres (Allred 1949). Sagebrush researchers were equally quick to see the potential of 2,4-D (Hull and Vaughn 1951). Hyder (1953) demonstrated its usefulness in eastern Oregon, and Hull and colleagues (1952) demonstrated its effectiveness in Wyoming.

With the benefit of hindsight it is easy to point out the many mistakes made in the halogeton control program. However, many of the concepts that we now use to judge success of a range weed control project were conceived as a result of the halogeton program.

L.M. Burge tested herbicides to control halogeton in 1944 (Burge 1955). Soil sterilization plots were established near Wells, Nevada, using borax and chlorate mixtures. Experiments were applied near Lovelock, Nevada, to test diesel-oil and diesel-water emulsions for halogeton control. Burge (1955) reported that he sprayed the sodium salt of 2,4-D on halogeton as early as 1945, a very early date for the use of 2,4-D on any weed.

As soon as the halogeton threat was recognized and funds became available, research trials of 2,4-D began in Nevada and adjacent states. Regulatory and management agencies and researchers interested in halogeton exchanged information through the Western Weed Control Conference. Burge (1946) described the nature of the halogeton problem at the 1945 conference in Sacramento. The 1946 conference featured discussion about the new wonder herbicide, 2,4-D, and an extensive program on halogeton.

In Idaho, a newly established project of the Agricultural Experiment Station and the Forest, Wildlife, and Range Experiment Station, entitled The Ecology and Control of Halogeton and Other Range Weeds, initiated studies in the early 1950s on the most effective selective herbicides among the three new heavy esters of 2,4-D (Erickson et al. 1952). Selective herbicides control a targeted species, while leaving another

species considered valuable as a crop or forage. The project also experimented with polybor and polybor chlorate soil-active herbicides. Soil-active herbicides enter plants through the roots rather than the foliage.

By the early 1950s the technology for controlling halogeton with 2,4-D was fairly well established and documented for Nevada (Palmer 1955), Idaho (Morton et al. 1959b), California (Talbert and Pryor 1951), Wyoming (Bohmont 1952), and Utah (Cook and Stoddart 1953). Based on trial and error, procedures were developed for treating infested sites, developing and calibrating application equipment, and training operators (Palmer 1955). The most critical factor was timing the applications. The substance had to be applied after spring germination but before the plants started sexual reproduction. The formulation and rate most generally recommended was 2 pounds per acre of a low-volatile ester of 2,4-D.

Burge was experimenting with aerial application of 2,4-D for halogeton control in 1952 (Burge and O'Harra 1952). Robocker and colleagues (1958) reported on trials with aerial applications but found that the 80-percent control was not sufficient to justify this procedure.

Miller (1956) conducted extensive research on herbicidal control of halogeton and seeding of wheatgrasses in Nevada, including evaluation of aerial applications of 2,4-D. He was concerned with the apparent lack of translocation of 2,4-D, meaning movement of the herbicide within the targeted species. Generally, the better the translocation the more effective a substance is in controlling the weed. Translocation was investigated by plant physiologists at Logan (Jansen and Cronin 1953, Cronin 1965).

In 1956, W.B. Ennis, head of the Weed Investigations Section, Agricultural Research Service, USDA, circulated a questionnaire to ARS scientists concerned with halogeton research, asking about the need for additional research to develop more effective chemicals for control. The consensus was that low-volatile esters of 2,4-D were the only effective postemergence herbicide treatments. There were two problems with 2,4-D: (1) high cost, at $3 to $4 per acre, and (2) lack of selectivity. If a new herbicide were developed, it would have to be (1) economical, (2) effective in low concentrations, (3) easily applied, (4) nonpoisonous to animals, (5) toxic to halogeton for several months, and (6) selective to the extent of being nontoxic to grass and shrub species. From a practical standpoint, the questionnaire resulted in a conclusion that spraying with any known herbicide could not be justified on more than 5 percent of an area infested with halogeton. Proper emphasis in research should be placed on biological and ecological control rather than herbicidal control.

Attempts to control halogeton with chemicals peaked in the early 1950s. From 1952 to 1954, the Nevada State Department of Agriculture sprayed 200,000 gallons of herbicides (largely weed oil) on 7,500 acres of rangeland. The Bureau of Land Management and the Bureau of Indian Affairs, of the U.S. Department of the Interior, plus the Nevada Highway Department, sprayed an equal amount of acreage (Burge 1955). Burge concluded he would need to treat 25,000 acres annually for 4 years, using 25 sprayers mounted on 4-wheel-drive trucks (figure 7), before the Nevada halogeton control program would begin to influence the critical livestock concentration points and the fringes of major halogeton infestations. From 1952 to 1955, 42,250 acres in Nevada were sprayed with herbicides to control halogeton (Miller 1956).

Interest in controlling halogeton with herbicides had largely died before second-generation herbicides were available for research and development (see Evans et al. 1979 for discussion on development of rangeland herbicides). Trials were conducted with substituted ureas (Cronin 1960, for example), and carbonate and triazine herbicides became widely available for research and development.

Martinelli and Evans (1969) developed procedures for use of atrazine to provide long-lasting weed control on road shoulders. Experiments were conducted in the Smoke Creek Desert of northwestern Nevada. In this arid environment ultra-low rates of atrazine effectively controlled halogeton on road sites for several seasons, as well as proving to be an economical and selective method in this specific environment.

The general use of soil-active herbicides on highway right-of-way weeds in the Intermountain Area has had a significant, and largely unnoticed, impact on halogeton populations. Between the edge of the herbicide-treated area and the low, cheatgrass-dominated plant community that occupied the roadside ditch is a zone where herbicides had not completely suppressed ruderal vegetation. Because of the location of this strip, it was thought that runoff water from the road surface would partially leach the herbicide outside the treated area. Russian thistle and, later, barbwire Russian thistle often dominated this community. On roadsides treated with atrazine, *Kochia scoparia* (L.) Schrad. replaced the *Salsola* species, apparently because it was slightly more tolerant of the herbicide. Essentially, these linear roadside communities rapidly invaded new locations.

L.A. Stoddart was an early and vocal opponent of eradication of halogeton (Stoddart et al. 1951a, Cook et

Figure 7. One of Lee Burge's herbicide spray rigs used to treat halogeton infestations in the 1950s

al. 1952). For many years he was professor and chairman of the Range Science Department at Utah State University, and he was a noted and widely respected range ecologist. He maintained that the issue of eradication was moot because halogeton had already successfully established itself in the sagebrush/salt-desert ecosystems. He suggested that the range livestock industry learn to live with halogeton and stressed the biological suppression of the weed by seeding perennial grasses. The control programs used in the 1950s simply left areas bare to provide more habitat for halogeton. The fact that 2,4-D was not selective toward native shrubs meant that indiscriminate spraying created more habitat for the weed. Reinvasion of halogeton into areas where it had been controlled was attributed to seeds that remained dormant in the soil during control projects and germinated in subsequent years.

Stoddart stated what became a principle of range weed control: Do not control a weed and leave an ecological void. Successful range weed control means replacing weeds with more desirable species.

Seeding

In 1943, a wildfire burned several hundred hectares of degraded sagebrush range east of Wells. A young range scientist, J.H. Robertson, who was with the Intermountain Forest and Range Experiment Station, then stationed in the Ruby National Forest, borrowed an old drill. Towing it behind an old truck, he drove around the burn trying to seed all of the representative soil types in the burned area. Later the area was invaded by halogeton. Robertson would take range managers on a tour of his meandering seeding and show them how wheatgrass plants excluded halogeton. Occasionally one of the openers on the old drill would skip over a rock and no wheatgrass plants would have become established. In these skips halogeton plants were found.

The discovery of halogeton, its spread, and the programs to suppress it coincided with a period of sudden change on the western rangelands. In tandem with the availability of herbicides, especially 2,4-D, technology was developed in the late 1940s to seed desirable perennial grasses on degraded sagebrush rangelands.

Widespread cattle grazing was initiated on the sagebrush/grasslands of the Great Basin in the 1860s, but only two decades later concentrated grazing in certain areas had depleted the perennial grasses and allowed nonpreferred shrubs to increase.

The impetus for reseeding degraded sagebrush came from two sources during the 1930s. First, the research stations of the U.S. Forest Service, especially the Intermountain Forest and Range Experiment Station headquartered at Odgen, Utah, developed techniques for seeding sagebrush rangelands. Second, the new Grazing Service of the U.S. Department of the Interior began to undertake range improvement projects.

During the late 1930s, surplus manpower was available through such programs as the Civilian Conservation Corps (CCC) for improvement projects on public

lands. For the first time the federal government was willing to spend considerable amounts of money on improving wildlands. Use of labor-intensive methods to rehabilitate degraded rangelands was defeated by the accumulations of woody biomass and the vastness of the land. The efforts of CCC workers who pushed hand planters through mature stands of sagebrush were futile because of unreduced biological competition from the shrub, the sheer physical restrictions of pushing the seeders, and the limited area that could be seeded even with large crews. Range rehabilitators faced the same problems that plagued homesteaders.

The successful homesteader in the sagebrush zone sometimes overcame the shrub communities by developing water supplies and flooding potential agronomic fields. The native desert shrubs could not stand wet feet. Thousands of homesteads were cleared by hand grubbing or by dragging rails or timbers over the land or by a combination of several such treatments. Range improvers did not have the option of flooding, and they had millions of acres of sagebrush to overcome and seed.

The CCC approached problems with a military attitude. More troops were futile, but the war against sagebrush would be more winnable if suitable equipment were substituted for manpower. The logical source of equipment was agriculture, but tillage implements generally proved too fragile and operations too time-consuming to use on sagebrush rangelands.

Borrowing from the techniques used by developers of irrigation tracts, the CCC experimented with dragging heavy railroad rails behind tractors to knock down or uproot mature, nonsprouting sagebrush plants and several brush plants. These included the "Monte Cristo rail," named for the Monte Cristo ranger district in the Wasatch National Forest, near Ogden; the "Olson rail," named for a sheep and wheat rancher who developed and used the rail for clearing sagebrush in the Columbia Basin north of Hanford, Washington; and the "Supp rail," developed by the Supp brothers to clear land in the defunct irrigation project at Metropolis, Elko County, Nevada.

These early attempts at seeding met with varying success. Most labor-intensive efforts of the CCC ended in failure. Efforts to revegetate abandoned cropland were more successful. In 1936, under the Emergency Relief Act, the Rural Resettlement Administration begin drilling the first of 57,000 acres of crested wheatgrasses on land utilization projects in the Curlew and Black Pine Valleys in Oneida County, Idaho. The Crooked River National Grassland in central Oregon on the east side of the Cascade Mountains was another center of success. Crews of local farmers were assembled to seed abandoned cropland. They brought their own teams and farm tractors to pull disks and moldboard plows and to seed with grain drills. A variety of species were seeded before crested wheatgrass became more or less the standard.

Crested Wheatgrass

The impact of World War I and of disastrous drought on a newly settled area caused tremendous social and political problems in the northern Great Plains (Lorenz 1986). A major conservation movement evolved at local, state, and national levels that helped restore settlers' dignity through preserving the soil, water, and grassland resources. Crested wheatgrass played a major role in this effort.

The first known introduction of crested wheatgrass into North America was made in 1898 by N.E. Hansen of the South Dakota Agricultural Experiment Station as a result of a plant exploration trip to Russia and Siberia for the U.S. Department of Agriculture. Here, he saw crested wheatgrass being tested at the Valuiki Experiment Station on the Volga River about 150 miles north of what is now Volgograd. He obtained a small amount of seed of five accessions (SPI Nos. 835, 837, 838, 1010, and 1012). In 1899, he distributed the original seed of one or more of these accessions to one recipient each at experiment stations in Alabama, Indiana, Michigan, Colorado, and Washington. No record has been found as to whether or not the seed was planted.

Hansen also supplied seed for a planting at Highmore, South Dakota, because Dillman (1946) reported that Johnston T. Sarvis, saw crested wheatgrass growing in forage crop nurseries there in 1906. The Highmore station was placed under new management and no record survived of any further distribution of seeds from Hansen's first introduction.

Hansen's second importation of crested wheatgrass came from the same source as his original collection and was sent in 1906 through the Moscow Botanical Gardens by Vasili E. Bogdan, director of the Kostichev Agricultural Experiment Station. The shipment contained five lots labeled *Agropyron desertorum* (Fisch.) Schult. (SPI Nos. 19537–19541) and one lot labeled *Agropyron cristatum* (L.) Gaertn. (S.P.I. No. 19536). Seed from one or more of these lots was distributed to 15 experiment stations from 1907 to 1913. These early importations have been implicated in the introduction of halogeton to the United States.

The introduction of crested wheatgrass to the United States and Canada was timely (Lorenz 1986). In both

countries, the stage was being set for producing a plant hero, which, like the settlers of the prairie, was an immigrant. The rapid settlement of the northern Great Plains of the United States and the prairie provinces of Canada between 1866 and 1920 and the demand for wheat during World War I led to plowing and cropping much land not suited as cropland. A concurrent series of extremely dry years with serious wind erosion and destruction of good soil led to abandonment of a tremendous area of farm land.

Crested wheatgrass was soon recognized for having the potential to rapidly establish a grass cover on this problem land. Its seedling vigor was better than most other species being used to revegetate. It rapidly developed a solid stand that could support grazing or haying operations. It readily produced a seed crop.

Efforts to increase seed was also started at an early date. Several research stations in North Dakota, South Dakota, and eastern Montana increased seed by careful management of very small quantities of seed and small plots. These stations were responsible for providing seed to other research locations and, in a limited way, to growers prior to 1921. There is an early record of 2-pound seed lots being distributed by the University of Saskatchewan in Canada. Several of the Canadian farmers were successful in increasing these small quantities to establish seed production fields. When the demand for seed developed in the United States in 1934, the Christianson Seed Company of Minot, North Dakota, bought seed in relatively small lots from many Canadian farmers and sold it to USDA for the regrassing program.

The first known range seeding of crested wheatgrass in the Intermountain Area occurred in 1932 on Herman Winter's farm near American Falls, Idaho, and at the USDA Sheep Experiment Station near Dubois, Idaho (Hull and Klomp 1966). As previously mentioned, in 1936, the Rural Resettlement Administration began reseeding in Idaho. Private ranchers also experimented with seeding sagebrush rangelands. In 1940 there were three successful seedings of crested wheatgrass on rangelands in Nevada—all on private ranches (Young and McKenzie 1982). Stewart (1938) described the crested wheatgrass from the first seeding as an oasis of perennial herbaceous vegetation in oceans of denuded rangeland.

During World War II, wool and meat producers pressured the Forest Service to allow more cattle and sheep to graze in national forests. Remembering the disastrous results of increased allocations during World War I, the Forest Service resisted the efforts but pointed out that livestock production could be increased if degraded areas were improved through seeding research with money from the War Productions Board. With the support of livestock producers, funding was greatly increased by Congress. The Forest Service seeded about 20,000 acres in this pilot program.

As a part of this program, J.H. Robertson was assigned by the Intermountain Forest and Range Experiment Station during the early 1940s to assess seedable sites on national forests in Nevada and Wyoming. In the Ruby Mountains of Nevada, Robertson suggested that the rugged topography, rocky soils, and general condition of the plant communities made seeding unfeasible. He suggested that seeding the degraded sagebrush ranges outside the national forests would benefit the higher ranges by permitting a later spring turnout date for livestock. His suggestion was accepted and 500 acres were seeded in the Ruby Valley near Arthur.

For many years the seeded area in the Ruby Valley had been a dangerous spring range for cattle because of low larkspur (*Delphinium*), a poisonous plant. The area's grazing capacity was rated at a marginal 20 acres per animal unit month. The seeded area was a mixture of private and public lands administered by the Department of the Interior. After 2 years' rest, the seeding was grazed for 3 weeks each spring by 400 cows and calves that normally would have been turned out on the national forests. This example of how the seeding money was spent by the Forest Service illustrates the potential of range improvement to alleviate management problems, improve degraded grazing resources, and increase red meat production. This and other pilot projects during the war helped dispel the prevailing attitude that sagebrush ranges could not be seeded (Young and McKenzie 1982).

As a result of the program, the Intermountain Forest and Range Experiment Station issued three landmark bulletins—on seeding Utah rangelands (Plummer et al. 1943), Idaho rangelands (Hull and Pearse 1943), and Nevada rangelands (Robertson and Pearse 1943).

Better Equipment

The Forest Service claimed a 90-percent successful establishment rate with pilot seeding. But equipment breakage was a major problem and led to formation of the Range Seeding Equipment Committee. A 1945 range seeding conference held in Utah and attended by western Forest Service administrators and researchers identified a lack of effective and suitable equipment as a major stumbling block in the way of successful seeding. Similar problems in other land management agencies eventually led to formation of a federal interagency committee for range seeding equipment.

Composed exclusively of Forest Service personnel for the first 2 or 3 years, the committee held its first official meeting in Portland, Oregon, in 1946. The second meeting, in Ogden, Utah, in 1947, included old-time range scientists such as George Stewart and W.R. Chapline and younger scientists such as A.C. Hull and Joe Pechanec.

The Bureau of Land Management joined the committee in 1949, followed by the Bureau of Indian Affairs of the U.S. Department of the Interior and the Soil Conservation Service of the U.S. Department of Agriculture. In 1954, after part of the range research program was transferred from the Forest Service to the Agricultural Research Service, ARS scientists joined the committee.

Brushland Plow

If sagebrush ranges were to be successfully reseeded, mechanical means of brush control had to be developed. Among the first projects undertaken by the committee was evaluation of the rail drags and pipe harrows. Both implements were relatively effective on old-growth plants, which could be easily uprooted, but not on supple, young plants.

The wheatland-type disk plow did the best job of controlling big sagebrush. Despite its drawbacks—continual maintenance from broken castings, disk, and even the frame if used on rocky sites—this plow established early seedings, including a portion of the Ruby Valley project.

After his experience with wheatland plows, J.H. Robertson was interested in developing a plow for rangelands. He had read about an Australian or Sungeneral stump-jump plow, which had disks that were independently suspended in pairs on spring-loaded arms so they rode over blockages rather than breaking. A plow was imported from Sunshine, Australia. It was tested on rocky and steep terrain in Idaho and the Pacific Northwest, but it was too weak and breakage was excessive.

From this prototype, the committee and the Forest Service Equipment Laboratory at Portland, Oregon, in 1947 and 1948, developed a plow known as the brushland plow. The engineering work was done by Ted Flynn, with assistance from Tom Coldwell.

Land managers now had an implement capable of attacking dense stands of big sagebrush. The Australian plow was relatively inexpensive, costing $413 plus freight in 1947 and weighing 2,900 pounds. The brushland plow weighed 5,900 pounds and was considerably more expensive—the cost continued to rise until it reached $25,000 in 1979, when manufacturing ceased.

The brushland plow was necessary to reduce competitive plants before a rangeland drill could be effectively used. The independent suspension of disks was roughly copied in the development of openers for the drill.

Rangeland Drill

Grain drills designed for farms had proven even less adapted to sagebrush ranges than plows. In southern Idaho and central Oregon, acres of abandoned cropland proved to be particularly hard on grain drills. The seedbeds were uneven with clumps of woody trash produced by the new brushland plows, as well as large rocks.

In 1951, John Kucera, a Forest Service staff officer in the Fremont National Forest in southeastern Oregon, volunteered to develop a rangeland drill that would eliminate the three or four daily breakages of drill arm assemblies. The drill conversion cost $1,000.

Development started in July 1951. As a performance goal, it was decided to build a drill that could be used anywhere one could drive a small crawler tractor. Up until that time most range seeding was done with John Deere-Van Brunt grain drills. The Fremont Forest had a Minneapolis-Moline drill with a heavy frame, so it became the experimental unit. To gain clearance, 12-inch spoke extenders were welded around the existing wheels, which prompted taunts that the experimenters were building a mechanical porcupine. A new rim was placed around the outside of the spokes. The designers then developed Y-yokes to support the disk openers, which made the furrows in the seedbed surface. Trial and error determined the correct angle that permitted these yokes to ride over obstructions.

The nemesis of the commercial grain drills had been breakage of the castings that attached the disk openers. This breakage was caused by side thrust as the disk dug into the seedbed. Kucera and his crew solved this problem with larger, cold-rolled steel shafts and welded plates to support the self-aligning bearings. Again, trial and error established the correct angle of the disk for optimum penetration in the soil.

After the flexible opener assembly, a boot was designed that collected the seeds from the drill box and conveyed them to the openers. The metal boot was connected to the opener with a rubber hose.

These were only the major modifications accomplished by the resolute Fremont Forest designers. A

host of other challenges, ranging from chains to raise the opener's arms to weights to make the openers dig into the ground, had to be considered and solved. Too, Lakeview, Oregon, was not an industrial center where material or design advice was readily available. There were 10 openers on the drill, so once a modification was perfected by trial and error, the designers had to make nine duplicates without drawings, templates, or jigs.

In the fall of 1951 the modified drill was used to seed 750 acres on the Coffee Pot Seeding in the Paisley Ranger District of the Fremont Forest. The openers worked adequately, but it was necessary to strengthen the frame and tongue. In early January the designers loaded what they called "our monstrosity" on a rail car to the Forest Service Equipment Development Center at Arcadia, California, where it served as a model for an engineered drill.

The Range Seeding Equipment Committee adopted the rangeland drill as a project in 1951. From June 1951 to October 1952, Tom Coldwell directed the engineering studies necessary to develop a prototype drill. On October 7, 1952, a full-scale engineering prototype rolled out of the shops at Arcadia. It was sent for testing to the Fremont Forest where it is still in use (fig. 8).

Once the drill was perfected, suppressing halogeton with crested wheatgrass plantings seemed assured. L.A. Stoddart of Utah State University was quick to point out the shortcomings of this program. He and the pioneer range ecologist George Stewart tempered the widespread enthusiasm with a reminder that not all halogeton sites could be seeded (Stoddart et al. 1951b, Stoddart and Cook 1951). Halogeton was adapted to portions of the sagebrush grasslands and salt-desert environments. Reseeding technology did not exist then nor does it exist now for salt-desert environments.

A second problem with seeding was that halogeton seedlings competed with wheatgrass seedlings. The herbicide 2,4-D is selective at rates that will control halogeton but leave the wheatgrass seedling. Trials to perfect seeding were reported by Miller (1956) and Cook (1965). Controlling the halogeton resulted in greater establishment of wheatgrass seedlings and higher subsequent yields. The improved seeding establishment was due to increases in available soil moisture from reduced competition (Cook 1965). Once established, a good stand of crested wheatgrass was very effective in biologically suppressing halogeton.

Frischknecht (1968) evaluated factors for controlling halogeton in grazed crested wheatgrass fields at the

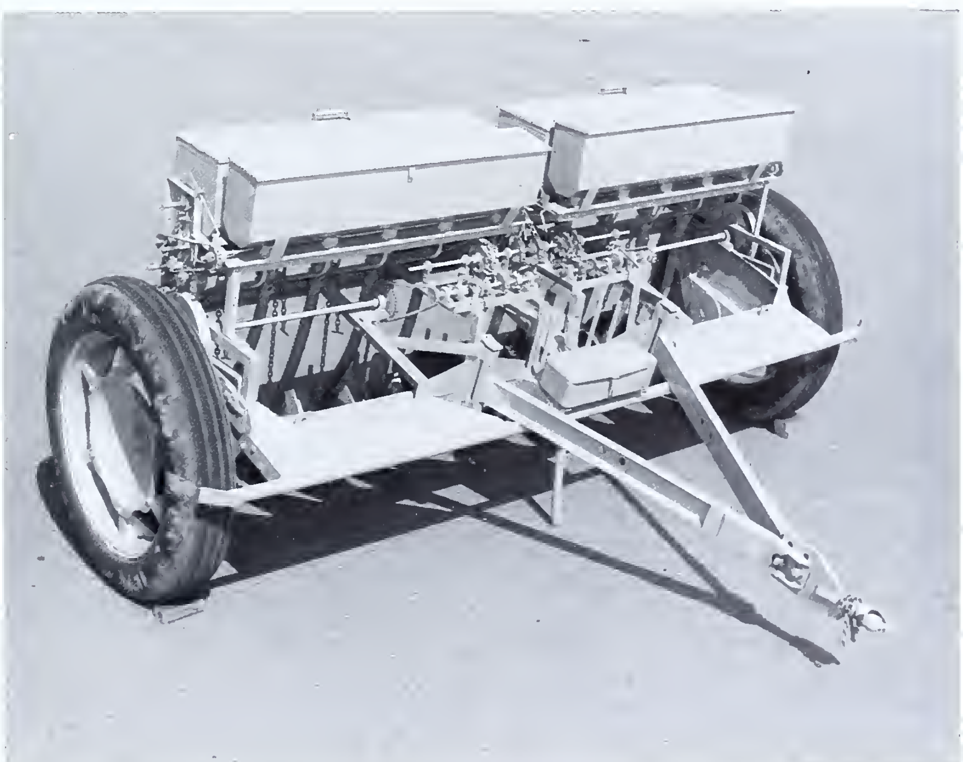

Figure 8. Rangeland drill

Benmore Experimental Area in Utah. The sites consisted of mosaics of coarser textured soils interspersed with islands of saline/alkaline slick spots. This was the same environmental situation studied by Cook (1961). Frischknecht found that occasional deferment of spring grazing was sufficient to reduce the abundance of halogeton.

In the late 1940s in Idaho, the response to widespread deaths of sheep from halogeton was the seeding of crested wheatgrass (Mathews 1986). Projects for suppression of halogeton varied from seeding small patches to a single seeding of more than 15,000 acres.

The Bureau of Land Management based its program in Idaho largely on the research of A.C. Hull, Jr. Starting in 1936, Hull conducted hundreds of seeding trials in Idaho and Utah while employed by the Intermountain Forest and Range Experiment Station. One of the brilliant young scientists at the station whose research eventually stopped the downward slide in the condition of the Intermountain rangelands, Hull was a contemporary of A. Perry Plummer, J.H. Robertson, and Jerry Klomp. Under the leadership of George Stewart and Joseph E. Pechanec, these scientists provided a means of enhancing the forage base for Intermountain rangelands and led the livestock industry out of a downward spiral.

Unfortunately, not all crested wheatgrass seedings were successful. In many sagebrush areas, cheatgrass proved to be extremely competitive with wheatgrass seedlings. The only reason that competition from cheatgrass was not a larger problem was extreme grazing pressure on the ranges, which biologically suppressed it. Many of the seedings intended to suppress halogeton took place on sites where crested wheatgrass proved unadapted. Often the soils contained excessive soluble salts, which deterred establishment of crested wheatgrass and enhanced growth of halogeton. Plowing to control brush completely eliminated competing vegetation, readying the sites for halogeton dominance. If seeding failed, the only thing accomplished was to put the halogeton in rows.

L.M. Burge expressed concern about unsuccessful range seeding as a means of spreading halogeton. He believed the herbicidal control program he championed offered more potential for controlling halogeton by eradication.

In May 1953, the Nevada State Board of Stock Commissioners passed a resolution to be presented to various cooperating agencies and a congressional delegation, requesting "continuing grass seedings on the public ranges to lands proven by reasonable test plots to be capable of producing acceptable grass" (Burge 1955) and seeking chemical weed control on areas not suited for seeding. Seedings consistently failed in saline/alkaline soil on the margins of the salt deserts.

Revegetating Salt Deserts

The problem with seeding the saline/alkaline soil was the commercial unavailability of adapted species. Several native shrubs, such as winterfat, were excellent browse, but artificial revegetation had proven extremely difficult. An ARS survey of halogeton research identified as being of the highest priority research on the seed and seedbed ecology of shrubs native to salt-desert environments.

Lee Sharp of the University of Idaho realized that technology had to be developed to revegetate degraded salt-desert plant communities if halogeton was truly going to be suppressed. He was instrumental in organizing the Salt Desert Shrub Range Revegetation Committee, which met in 1958, and included participants from the Universities of Nevada and Idaho, the State University of Utah, and management agencies.

Besides life history and reproductive ecology studies, Sharp proposed that the committee study the relationships of rodents and insects to salt-desert species. These goals were well ahead of their time. Apparently, the committee did not meet after 1958, or if it did, the proceedings had limited distribution.

The Bureau of Land Management sponsored a series of important symposiums for understanding rangeland resources: cheatgrass and crested wheatgrass symposiums were held at Vale, Oregon (Young et al. 1987), and a salt-desert shrub symposium was held at Cedar City, Utah, in 1966. At this meeting, Neil West, who was to become a noted natural resource ecologist at Utah State University, suggested that the participants be glad that halogeton was introduced to salt desert shrub ranges because it focused attention on the 40-million-acre resource which had been largely ignored by previous range research (West 1966).

A. Perry Plummer of the Intermountain Forest and Range Experimental Station also took part in the symposium, reporting on 25 years of experience with artificial revegetation in salt-desert situations. He said that the chances of artificial revegetation were slight with less than 8 inches of precipitation (Plummer 1966).

Later Plummer journeyed to Russia as part of a team searching for adapted plant materials. Out of this visit a chenopod semishrub, *Kochia prostrata* L., was introduced. At various times it has been suggested as the best species for revegetating salt deserts. The plant can

persist in the harshest conditions found in the temperate deserts of the Great Basin after it has become established by transplanting the seedlings. However, it has generally been difficult to establish by direct seeding. Plants established by transplantation produce seeds that do establish naturally. Some say that this species may be too competitive and would invade native plant communities if widely planted in salt deserts.

K. prostrata has a wide distribution in Europe and Asia and exhibits considerable taxonomic diversity (McArthur et al. 1990). It competes successfully with cheatgrass and recovers after burning in wildfires. Artificial seedings in cheatgrass communities have been successful (Monsen and Turnipseed 1990). Seedlings have been successfully established by direct seeding in halogeton stands in Utah.

Species of winterfat (*Ceratoides*) occur in central Asia, eastern Europe, and South America, as well as North America. J.H. Robertson collected seeds of exotic species of *Ceratoides* from throughout the world and grew them in a common garden at Reno in the early 1960s. The Pamir Research Station of the USSR and the Academy of Science supplied the seed despite the Cold War. A similar garden containing 22 species of *Ceratoides* was established at the Knoll Creek Field Station of the University of Nevada in Elko County. A single species survived and showed promise of being a desirable forage species. It was introduced as Pamirian winterfat (*Eurotia ceratoides*). The generic name was changed to *Ceratoides* so the specific name had to be changed to *latens*.

Robertson's motive in assembling the *Ceratoides* garden was to find an exotic species that would be more competitive in the Great Basin than endemic species. By the time the adaptation of Pamirian winterfat was realized, the halogeton crisis had passed, and the species, despite promising trials, was never widely planted.

Attempts to avoid oxalate poisoning are presently based on screening exotic forage adapted to salt-desert ranges for oxalate content (see Davis 1979, for example) and identifying weedy species which are oxalate accumulators but that have not yet been introduced to the United States.

Lee Sharp tried to interest his students in the biology of salt-desert shrub communities and especially in factors that influence stand renewal in instances where species of plants had catastrophically died over a vast area. Insects, disease, and drought were all factors that could lead to widespread losses of shadscale stands. Richard Eckert, Jr., pointed out that senescence in winterfat plants may be related to the activities of big-headed grubs (*Acamaeodera* sp.), which destroy the stems. This insect is responsible for controlling the population dynamics of green rabbitbrush populations (Young and Evans 1974). Recently, ARS scientists found the grubs to be active in the stems of the native chenopod *Allenrolfea occidentalis* (unpublished research).

In the 1980s there were significant changes in stand renewal of salt-desert plant communities of the Great Basin. The spread of cheatgrass brought wildfires to these communities as a means of stand renewal, apparently for the first time. When first published, this concept created considerable controversy; senior land management and high-level agricultural extension personnel thought the idea was mistaken, based on their experience with the Great Basin (Young et al. 1987). Catastrophic stand renewal in the salt-desert environment provides the opportunity for the spread of aggressive annual species such as halogeton or for the introduction of the next alien species.

The severe and prolonged drought of the late 1980s and early 1990s created habitat for halogeton by reducing cheatgrass dominance of degraded big sagebrush/bunchgrass rangelands. Currently, many students are interested in restoring the native vegetation of Intermountain rangelands. Several million acres have been artificially seeded to introduce wheatgrasses or mixtures of introduced and native species, but very few, if any, successful seedings have been made to restore native plant communities. Lack of understanding of the basic biology of the species involved and competition from accidentally introduced weeds make such restoration attempts very difficult.

Chapter 11. Biological Control

Halogeton appeared to be the type of pest that would be susceptible to biological control. The classic example of biological control of a weed species is exotic prickly pear (*Opuntia* spp.) in Australia (Huffaker 1959). In the United States the outstanding example is Klamath weed (*Hypericum perforatum* L.) in California. C.B. Huffaker, of the Department of Biological Control, University of California, Berkeley, played a prominent role in the Klamath weed program and suggested biological control as the key to suppressing halogeton.

Early Exploration

In 1956, the Agricultural Research Service (ARS) weed research program received $77,000 in increased appropriations. Of this, $20,000 was transferred to the Entomology Research Division to explore the native habitats of halogeton for possible insect biological control agents. According to W.B. Ennis, former leader of weed research, funding gradually increased to $23,687 in 1963.

During 1956, surveys for insects that attack halogeton were conducted in Spain, Syria, Iran, Afghanistan, and India by George Voight, Clifton Davis, and Jack Drea (Davis 1957, Voight 1957). The search for insects was centered in the Middle East, and a USDA station for halogeton research was established in Tehran under the direction of Jack Drea.

The itinerary of Voight and his colleagues began in southern Spain (near sea level) in late March and proceeded to Syria via Lebanon, central and northern Iran, north-central Afghanistan, and via New Delhi to the Indus Valley (10,000 feet elevation) in Ladakh. The itinerary was then reversed over the same route, except Syria.

Voight and his associates identified five species of *Halogeton*: *H. sativus* in Spain, *H. alopercurades* in Syria (which they considered to be perennial), a possible *Halogeton* in Iran (not sure of genus), *H. glomeratus* in Afghanistan, and *Halogeton* sp. in Ladakh. The plant from Iran was finally identified as *Seldlitzia florida* var. *mucronata* Aellen.

Davis visited Dr. Paul Aellen in Basel, Switzerland, in 1957 seeking assistance in identifying the numerous chenopods encountered. At each location, related chenopods (especially in the tribe Salsoleae) were studied for insects. Altogether 80 to 120 species of insects were found, affecting 18 to 20 species of the tribe Salsoleae. *H. glomeratus* was never found in sufficient density to support a significant insect population (Voight 1957). Voight explored the Gurgan-Gunbad section of the Caspian Sea in Iran without finding halogeton, but he did find an unidentified species of halogeton in southern Iran. The only *H. glomeratus* found was at high elevations in mountain cliffs near Bamian, Afghanistan.

The Bamian Valley has an annual precipitation of about 10 inches. Here, halogeton was found in very localized populations. Six small colonies were discovered, widely spread up and down the valley from elevations of 6,599 to 7,000 feet. The colonies were all associated with near-vertical cliffs in sedimentary formations. Half of the colonies died from drought before seeds were produced (Voight 1957).

A basic problem in searching for insects for biological control is identification of the specific plant taxon to be controlled. Insect pests can be extremely specific in their host requirements. In the case of halogeton, such a search was complicated by two factors: (1) the taxonomy of a relatively unknown genus such as *Halogeton* was quite vague, and the taxonomic literature was almost entirely in Russian, and (2) the genetic makeup of the halogeton spreading in western North America might not match any native taxon in central or southern Asia. Any difference in genetic makeup could be due to the probable introduction of a very restricted genetic base into a new environment where the species expanded at a tremendous rate without natural enemies. Presumably, the species also could have evolved rapidly.

These taxonomic problems were confounded when the halogeton biological laboratory moved from Iran to Rabat, Morocco, from 1959 to 1963. Insects were collected in Spain and Morocco, with no chance to collect from *H. glomeratus*, since the species does not occur in either of those places (personal communication, Lloyd Andres, November 16, 1981).

Many insect species were collected in the Near East and North Africa, but many of these voraciously attacked sugar beets in a feeding test and were thus unsuited for introduction. Sugar beets are members of the Chenopodiaceae family and are an economically important crop in the Intermountain Area. A weevil, *Cosmobaris americans* Casey, is considered, despite the specific name, to have been introduced from Asia to North America where it attacks sugar beets and halogeton among the chenopods (Landis et al. 1976). The sugar beet probably evolved in Asia and has a host of pests that share related plants, such as halogeton, as prey.

Holloway (1959) reported on experiments conducted to determine the specificity of a moth, *Heterographis fulvobasella* Ragonot, which damages *Halogeton sativus*

in Morocco. The moth appeared to be sufficiently specific to be considered for introduction. The ARS insect identification and parasite introduction researchers reported in 1962 that in greenhouse testing the females refused to lay eggs on *Atriplex, Eurotia, Salsola, Triticum, Oryzopsis, Secale, Hordeum, Bromus, Avena,* and *Lycopersicum*. They readily laid eggs on *H. sativas* but refused to lay on *H. glomeratus*. The entomologist felt this failure might have been because the greenhouse-raised plants grew only ½ inch high before flowering. The entomologist changed the photoperiod, but the insect still did not care for *H. glomeratus* (Frick 1962).

The entomologist based in Morocco doubted that any progress could be made on biological control in North Africa and suggested the project be moved to Rome. The Weed Investigative Unit also had doubts about the possibility of biological control after 8 years and $156,079 and no longer supported the program.

USDA established a cooperative agreement with the Commonwealth Institute of Biological Control (CIBC), Rawalpindi, Pakistan, in 1963. CIBC was to search for insects attacking *Halogeton* and *Salsola*. This project continued until 1975 (personal communication, Lloyd Andres, November 16, 1981).

As the final step in the first phase of the halogeton biological control program, the moth *Heterographis fulvobasella* was introduced to the United States in 1964 and quarantined. It was found to be insufficiently host-specific to be released (personal communication, Lloyd Andres, November 11, 1981).

In yet another attempt to obtain insects, ARS sent L.A. Andres to Uzbekistan and Kazakhstan, USSR, in 1965. Halogeton plants were found only in limited numbers due to drought. Plants were found on lowland saline environments along the Amu Darya River in Uzbekistan and were associated with *Artemisia* sp. on high plateau areas of Kazakhstan. A number of natural insect enemies were noted, but results of the survey were never fully evaluated. Russian botanists expressed the opinion that *Halogeton* was limited by competing native vegetation in central Asia. Political difficulties made return trips to Russia impossible (Andres, personal communication, 1981).

A Promising Moth

CIBC initially began studies of the biological control of halogeton by studying the complex of insects attacking *Halogeton falconeri* Clarke, in northwest Pakistan (Simmonds 1967). *Coleophora* sp. larvae were found to be actively feeding in *Salsola* stems from May to September at Warsak near Peshawar, Pakistan. Flowers developed on the stems, but failed to set seed.

Coleophora klimeschiella Toll. was discovered as a natural enemy of *Salsola ruthenica* Iljin and also would attack *Halogeton glomeratus* (Khan and Baloch 1976). *C. klimeschiella* occurs in Turkey on *S. iberica* = (*S. australis*), the Russian thistle of western North America. Extensive laboratory and field testing showed the insect was host specific for *Salsola* and completely ignored the valuable chenopods (such as sugarbeets). The only other plant species where the insect laid eggs were *Kochia indica* Wight, *Chenopodium album* L., *Portulaca olerceae* L., and *H. glomeratus*.

Apparently *C. klimeschiella* was not released in the United States. The related species *C. parthenica* Meyt. was widely released in 1975 in halogeton-infested areas in the western United States. Subsequent checks of the release sites, into 1980, failed to find evidence of successful establishment (Andres, personal communication, 1981). Releases of *Coleophora* were successful in controlling *Salsola australis* on the west side of the San Joaquin Valley in California.

One of the release sites for *Coleophora* in Nevada was Dodge Flat, a range sheep concentration site near the railroad shipping pens at Wadsworth. Lloyd Andres drove with the insects from the ARS laboratory at Albany, California, to Reno. They did not establish. L.M. Burge had crews spraying 2,4-D on halogeton and the native shrubs at Dodge Flat in the 1950s. Barbwire Russian thistle invaded the sites during the 1970s and partially suppressed halogeton.

Khan and Baloch (1976) reported that during field research in Pakistan two morphologically distinct forms of *Salsola ruthenica* were observed: a short-leaved form near agricultural fields and a long-leaved form among the desert shrubs. *Coleophora* species were specific for each type. At Dodge Flat the same morphological distinction is apparent with *S. australis* on agricultural lands and *S. paulsenii* in the desert. It was probably lucky the insect failed to establish because *S. paulsenii* suppressed halogeton on the site.

So ended 20 years of biological control research on halogeton. Since that discontinuation, there has been considerable enhancement of biological control research through the use of plant pathogens to control weeds. We do not know if these techniques have application to halogeton control. Annual plant species are relatively poor candidates for biological control by introduced insects, compared with perennials where the insect can overwinter in the host species. The number of important crop species that are members of

the same plant family as halogeton were an additional problem with biological control. The large number of native, landscape-characterizing chenopod shrubs in the infested area also made classical biological control very difficult. Failure to find expansive stands of halogeton in central Asia made the chances of finding suitable insects for biological control very remote. This does not mean that the basic concepts of biological control are false, but it does point out that not all introduced weeds can readily be suppressed this way.

Chapter 12. The Political Arena

The spread of halogeton was viewed as such a basic threat to the livestock industry that it caused political repercussions from the western sagebrush range states to Washington, D.C. Halogeton meant money during the 1950s—money for control programs, for range improvement, and for research.

State Efforts

In Nevada, L.M. Burge was responsible for focusing attention on the problem. From 1947 to 1950 the Nevada State Department of Agriculture conducted a halogeton control program using department funds. By 1950 at least 750,000 acres were known to be infested, and Burge asked the 1951 Nevada legislature for funds to help control the spread (Burge 1955).

Nevada approved legislation on March 22, 1951, authorizing the state department of agriculture to conduct studies on *Halogeton glomeratus*, which included distribution and prevalence, poisonous properties for livestock and means of combating them, and methods of control under various conditions. The department was authorized to cooperate with any agency, corporation, or individual interested in controlling halogeton. The initial appropriation was $20,000.

The department established a state Halogeton Control Committee on April 23, 1951, to develop an overall control policy. The committee consisted of representatives of county, state, and federal agencies. Included were the Nevada's Cattleman's Association; the Western, Southern, and Union Pacific Railroads; the University of Nevada; Toiyabe National Forest; the Bureau of Indian Affairs; and the Civil Aeronautics Authority.

Burge used the Western Weed Conference as a vehicle to drum up interest in controlling halogeton. The 1950 conference met in Denver, where he lobbied for a program to channel research in the infested states through one organization (Burge 1950). Representatives of 13 federal agencies, which controlled 400 million acres of public land in the western states, were in attendance.

A coordinating committee of the conference presented a four-point program, which the conference adopted. This report asked for federal legislation authorizing the Secretary of Agriculture to designate one federal agency that would enter into cooperative weed-control agreements with the various infested states. Burge had the report endorsed by the White Pine County (Nevada) Farm Bureau, Nevada Sheepmen's Association, Nevada Wool Growers Association, Nevada State Veterinary Association, Modoc County (California) Farm Bureau, Western Plant Board, Idaho Cattle and Sheepmen's Association, and Idaho Sugar Beet Growers (Burge 1950).

He appealed to the Nevada Cattlemen's Association to support the proposed legislation. The association president, a rancher in Wells, in the heart of the halogeton infestation, replied that he was not in favor of increased government spending no matter what the cause.

The proposed federal-state program embraced the following four goals:

1. Ascertain the size and extent of the weed infestation through uniform and adequate surveys.
2. Control critical areas.
3. Employ good land-management practices.
4. Increase research on control measures.

Burge prevailed upon U.S. Representative Walter Baring to introduce the program in Congress.

The executive committee of the Western Weed Control Conference met in Boise, Idaho, in 1951, and again demanded that the federal government adopt an extensive program of halogeton control (Burge 1955). The committee recommended that Congress appropriate $5 million (Burge and O'Harra 1952).

It appeared that the Bureau of Land Management (BLM) would get $2 million to combat halogeton, and in July 1951, agency representatives met in Salt Lake City to discuss plans for implementing the proposed bill (Burge and O'Harra 1952). According to BLM Director Marion Clawson, the agency had sold the seeding program to Congress as the best method to control halogeton. This seeding program may have been one of Clawson's greatest contributions in a long and distinguished career as a concerned environmentalist.

Early in 1951 the public relations department of the Richfield Oil Corporation voluntarily approached the Nevada State Department of Agriculture to offer its counsel and financial aid for the study of Nevada's halogeton problem (Burge and O'Harra 1952).
The two groups agreed that the many pressing problems confronting livestock operators and the agencies responsible for halogeton control could best be served by a research grant, unencumbered by restrictions, to be used at the department's discretion. Charles D. Jones, president of Richfield Oil, provided $10,000 to fund the grant. The money was used principally to survey the extent and nature of infestations in north-

eastern Nevada and to publish a bulletin of the Nevada Department of Agriculture. The factors that influenced the grant are not clear.

Also in 1951, the Nevada Department of Agriculture sprayed more than 225,000 gallons of material—largely hydrocarbon oil emulsions—on halogeton. The price of the oil was probably slightly more than half of the $10,000 grant. The grant changed the balance of range research funds in Nevada, making the Nevada Department of Agriculture the important research organization in the halogeton battle. The Richfield Halogeton Committee was formed, consisting of L.M. Burge, Edward Records, and G.G. Schweis, all of the Nevada State Department Agriculture; C.E. Fleming, Agricultural Experiment Station, University of Nevada; F.W. Groves, State of Nevada Fish and Game Commission; and A.H. Bronson and G.L. Randall, Richfield Oil Corporation, Los Angeles. The committee was established July 13, 1951.

A second Nevada halogeton committee was organized in order to prevent duplication and unify halogeton research. Apparently, the committee designated itself as the clearinghouse for halogeton research, which was the start of prolonged animosity among the Nevada halogeton researchers.

BLM began to make funds available for halogeton control in the fall of 1950 when $75,000 was allocated for seeding halogeton-infested rangelands in southern Idaho (Platt 1952). In October and November, BLM seeded 11,500 acres of crested wheatgrass in the Raft River Valley. The Agricultural Experiment Station and the Forest, Wildlife, and Range Experiment Station of the University of Idaho jointly started a project entitled The Ecology and Control of Halogeton and Other Range Weeds, funded largely by federal agencies (Erickson et al. 1952).

In the fall of 1950, Utah Commissioner of Agriculture Tracy R. Welling called state range users and county, state, and federal experts to his office in Salt Lake City. Welling compared the halogeton outbreak to an outbreak of Mexican hoof and mouth disease. In reporting Welling's news conference, the *Reno Journal* (November 29, 1950) stated that the introduction of halogeton was communist sabotage. The Russian press had been claiming that the United States introduced the Colorado potato beetle to East Germany. Attending the meeting was Ward T. Hoffman, billed as USDA's top expert on poisonous plants. Hoffman spent the summer studying halogeton at the USDA experiment station at Salina, Utah.

The Utah State Department of Agriculture also organized a halogeton control committee that published a list of more than 50 halogeton advisers. L.A. Stoddart and George Stewart worked to involve the Society for Range Management in the halogeton control program. Stoddart championed a sound ecological approach to the control program and believed range managers should adopt such an approach as professional standards.

Halogeton infestations in California were confined to the Department of Defense facility located at Herlong. In 1951 the Department of the Army allocated $2,000 for control. Although the Department of Defense was more than willing to control noxious weeds on its land, halogeton provided a fireproof cover on most of the ammunition bunkers half buried in the salt desert of the Herlong Ammunition Depot. This use was not official policy. It was, however, the use proposed for halogeton by J.H. Robertson before the plant was determined to be toxic.

As soon as the first spot infestation of halogeton was discovered in Colorado, Governor Dan Thornton, Commissioner of Agriculture Paul Swisher, and Secretary Brett Gray of the Colorado Wool Growers Association organized a campaign to contain the spread of the plant (LaCoste 1953).

Western senators had a hard time convincing the federal government in Washington, D.C., that halogeton was a crisis. Senator Duorchak of Idaho reported that the Bureau of the Budget would not release funds for halogeton control until the next budget for BLM was considered in 1951 (*Reno Gazette*, May 30, 1950). Speaking at the Western Governors Conference, powerful Pat McCarran, U.S. senator from Nevada, focused the governors' attention on the halogeton problem (*Reno Journal*, March 31, 1951).

Washington Gets the Message

Despite state and regional efforts to draw attention on the problem, it took an illustrated article in *Life Magazine* to make halogeton a national issue ("Sheep-Killing Weed," July 15, 1951, pp. 55–56). Photographs showed bare-boned sheep carcasses strewn across the salt desert and a recently poisoned ewe lying in the foreground while another ewe nibbled an innocent-appearing halogeton plant in the background. The article commented that halogeton could be suppressed through proper range management.

A scientific article reported that at least 12 sheep operations had been forced out of business in southern Idaho (Stoddart and Cook 1951).

The *Life* article was preceded by a *Newsweek* science article (December 4, 1950), but that report was overshadowed by a story about America's original atomic pile and a scientific breakthrough on "Lobsters in

Love." Later, national publicity was obtained from a *Reader's Digest* article based on a *Denver Post* article.

The western congressional delegations had been busy in Washington, D.C., lobbying for a federal program. Senator George W. Malone from Nevada introduced a letter into the *Congressional Record* on August 23, 1951, signed by R.H. Schwartz, president, Nevada State Farm Bureau, and Fred H. Dressler, president, Nevada State Cattle Association, stressing the need for funds. Senator George Molone introduced the *Halogeton glomeratus* control bill in 1951. It was jointly sponsored in the House of Representatives by Reva B. Bosowe of Utah and Walter Baring of Nevada (LaCoste 1953).

In a letter to Senator Joseph C. O'Mahoney, chairman, Committee on Interior and Insular Affairs, dated June 14, 1951, Secretary of Agriculture Charles F. Brannan stated that the Forest Service experiment stations would require $25,000 annually to conduct research on halogeton. At that time experiment stations employed the only federal range researchers. Secretary Brannan reported that halogeton was not growing on Forest Service lands at that time but that many other poisonous plants in the national forests were causing serious economic losses. He estimated that halogeton control measures were required on 439,000 acres of national forest at a cost of $500,000 annually for 10 years (82nd Cong., 1st sess., June 1951, S. Rept. 578).

Secretary Brannan suggested that if the halogeton control bill passed, a research program could be initiated by the Bureau of Plant Industry, Soils, and Agricultural Engineering that would encompass both ecological studies and the development of control measures. Ecological studies would include such life history considerations as emergence, seed formations, seed movement, dormancy and viability, root systems, growth requirements, production, competition with other plants, soil relationships, and physiology of oxalate formations. Control studies would include a thorough screening of available herbicides for kinds, rates, stage of growth for herbicide application, and methods of application, as well as other methods such as burning and blading. He thought about $50,000 would be needed.

Assistant Secretary of the Interior Dale E. Doty sent a letter to Senator O'Mahoney objecting to the bill as written in 1951, since funds would be under the control of the Secretary of Agriculture. As originally introduced, the bill (S. 1041) authorized a general program for the eradication of all noxious weeds. Two identical bills were introduced in the House (H.R. 1933 and H.R. 2052). The Bureau of the Budget objected to this blanket approach, and an amended bill was restricted to halogeton only (82nd Cong., 2nd sess., July 14, 1951, H. Rept. 2447).

K.T. Hutchinson, assistant secretary of agriculture, in a letter to Harold D. Cooley, chairman, House Committee on Agriculture, dated April 28, 1952, pointed out that the Department of Agriculture already had statutory authority to control insect and plant pests and stated that that authority was adequate to conduct research on halogeton. He said the Department of Agriculture had no objection to the Department of the Interior receiving authority to control halogeton on its own lands. The final bill, which passed, was amended to reflect the various objections.

A Bill Passes

The act passed July 14, 1952 ("Providing for the eradication and control of Halogeton glomeratus on lands in the United States," Title 7, U.S. Code, secs. 1651–1656) and was signed by President Truman. The act authorized the Secretaries of Agriculture and of the Interior to conduct surveys to detect the presence and effect of halogeton and to plan, organize, direct, and carry out methods to control, suppress, and eradicate the stock-killing weed. Infested states had to devise cooperative programs before federal monies could be spent.

The federal government never directly appropriated any funds for halogeton control as prescribed in the act. The original Senate bill S. 1041 had a companion bill, S. 980, that called for appropriating $250,000 for the eradication and control of halogeton on *public* lands for the fiscal year ending June 30, 1952. USDA's contribution was confined to surveys and research. The U.S. Department of the Interior spent a great deal of money for range improvement and contributed lesser amounts to halogeton research. Various agencies under the Department of the Interior contributed to local control programs for halogeton (for example, the Bureau of Indian Affairs and BLM).

In 1952, the budget of the USDA Bureau of Plant Industry, Soils, and Agricultural Engineering included $40,000 to develop methods for controlling halogeton and other noxious weeds.

BLM was putting the federal halogeton funds to use by 1952. In Nevada, survey crews located spot infestations along U.S. 40 in Paiute Meadows and Pumpernickel Valley in Humboldt County and in Buena Vista Valley, Seven Troughs, and Lovelock in Pershing County. In Paradise Valley 14,000 acres of halogeton-infested big sagebrush were plowed with wheatland plows in preparation for seeding with crested wheatgrass (*Reno Gazette*, October 15, 1952).

As a part of this program, scientists E.H. Cronin and L.L. Jansen began work in Logan, Utah, in 1952, Charles Robocker initiated research at Reno in 1953,

and R.H. Haas started work at Burley, Idaho, in 1953. Cooperative agreements were developed among the Utah, Nevada, and Idaho Agricultural Experiment Stations, the Bureau of Land Management, and the Forest Service. Research was coordinated on a regional basis. In Utah, emphasis was given to physiological and anatomical research aimed at herbicidal control. In Nevada, a program of ecological research was planned including microenvironmental studies. Experiments in Idaho emphasized field studies of methods of control, the relation of different soil factors to the occurrence, growth, and chemical composition of halogeton, and the effects of halogeton residues on soils.

The scientists employed by what was soon to become the Agricultural Research Service were not trained as range scientists. For halogeton research, USDA had largely chosen plant physiologists.

R.K. Pierson, chief, Division of Soil Moisture Conservation, Bureau of Land Management, estimated that BLM had 885,000 acres infested with halogeton (Pierson 1952). Passing through BLM lands were 1,200 miles of railroad right-of-way and 9,000 miles of roadway lined with halogeton. BLM planned to use herbicides on these right-of-ways. The main control procedure planned was seeding to perennial grasses. BLM appropriations in 1952 permitted planning for 163,000 acres of seeding. BLM had already seeded 89,000 acres of this total. According to Pierson, the major problem facing BLM was the vast area of salt-desert ranges infested with halogeton for which no seeding technology or adapted revegetation species was available.

In 1954, BLM appraised all of the halogeton control seedings in cooperation with the state halogeton committees (Palmer 1955). Based on a sampling procedure developed by ARS range scientist Don Hyder for evaluating the success of seedings, BLM evaluated about 225,000 acres of wheatgrass seeding for halogeton suppression in Nevada, Idaho, Oregon, and Utah (table 2). Appraisal and inspection committees believed the percentage of good and excellent stands would increase as seedings matured. The major cause given for seeding failure was selection of sites that were not adapted to wheatgrass species. Too, often there were irregular salt-desert communities within sagebrush communities.

BLM estimated the halogeton seedings resulted in a net increase of 13,131 animal unit months (AUMs) of grazing on the range (Palmer 1955). The example given was the John Ward seeding in the Raft River Valley near Almo, Idaho—the same John Ward who suffered the large kill of sheep in 1945 (and supposedly went out of business). Ward seeded 1,200 acres in

Table 2. Bureau of Land Management ratings of wheatgrass seedings in Nevada, Idaho, Oregon, and Utah for their potential to suppress halogeton, 1954

Rating	Acres	Percentage of seedings
Excellent	79,000	33
Good	45,000	21
Fair	42,750	19
Poor	33,250	15
Failure	23,250	12

cooperation with the Idaho State Department of Agriculture and BLM. Before seeding, the area produced 30 lb/acre of forage, or 30 acres to support one AUM. In 1952, the Ward seeding had virtually crowded out halogeton and was producing 1,200 lb/acre or 0.7 acre per AUM.

The typical successional pattern of halogeton in wheatgrass seedings in Idaho was estimated as follows (Palmer 1955):

Sequence in Wheatgrass Seedings	Frequency of Halogeton (%)
Before seeding	10.0
Seedling year	15.1
Second year	15.7
Third year	3.3
Maturity of wheatgrass stand	1.0

Halogeton never completely disappears from a stand but it is greatly suppressed, and the increase in available forage makes the chances of poisoning minimal.

The excellent BLM publication "Can We Control Halogeton?" concluded that chemical control was suited only for spot treatment of new infestations and recommended that BLM increase support for research by state and federal agencies (Palmer 1955).

Halogeton remained an important issue in the Intermountain Area during the early 1960s. Livestock losses in Idaho, Nevada, and Utah increased steadily from 1,064 in 1958 to 1,793 in 1960 to 3,840 in 1961. The 1961 losses were valued at $81,280.

Halogeton faded from the newspapers during the late 1960s. By 1965, seeding had virtually ceased on BLM-controlled rangelands.

In January 1971, like a ghost from the past, halogeton returned to the headlines of the *Salt Lake City Tribune*:

More than 1,200 sheep in a herd of 2,400 had died of unknown causes in less than 24 hours near the town of Garrison on the Utah-Nevada border. But halogeton was not immediately credited as the cause of the kill. In 1968, near the Department of Defense's Dugway Proving Grounds at Dugway, Utah, 6,400 sheep were instantly killed by aerially applied nerve gas due to a sudden shift in winds (Williams 1973). In January 1971 an article in *Atlantic Magazine* stirred an old controversy concerning sheep deaths from fallout from atmospheric testing by the Atomic Energy Commission in Nevada during the 1950s. It is little wonder that halogeton came in a distant third as the cause of the Garrison kill.

Governor Calvin L. Rampton and Utah State Veterinarian James F. Schoenfield realized that the Garrison kill was potential political dynamite. They quickly summoned the poisonous plants experts from the USDA, ARS Poisonous Plant Laboratory, at Logan, Utah. Wayne Binns, director of the laboratory, repeated the old facts—about halogeton's discovery and determination of toxicity—to a new generation of reporters (*Salt Lake City Tribune*, January 23, 1971). A familiar story emerged. The sheep were grazing on desert winter range, with snow as a source of water. The herd moved up slope following the melting snow. On the night they died, the sheep were bedded on a badly overgrazed area that was practically devoid of vegetation (Williams 1973[1]). Hungry animals roamed downhill into a dense patch of halogeton. The halogeton was exceptionally poisonous, with 36 percent soluble oxalates in the leaves. Each animal consumed two to three times the amount of halogeton required to cause death.

Williams considered the size of the Garrison kill fairly unusual but pointed out the 1945 Ward kill of 1,620 out of 1,700 animals, the 1940s Raft River Valley kill of 275 and 750, and the 1,100 sheep killed near Strevell, Idaho. In Utah, 850 sheep died in 1964 in Box Elder County, and losses of 200 to 400 were normal in western Utah.

Halogeton showed a remarkable resiliency for political controversy during 1980 and 1981 when it surfaced as a prominent issue during evaluation of the environmental impact statement for the "race track" mode of basing the MX missile system. The construction of the system in Nevada and western Utah would probably have created a huge habitat for halogeton. Revegetation contractors, largely without experience in salt-desert situations, suggested procedures to mitigate the original impact of the MX system on the desert environment. Unfortunately, we knew little more about revegetating salt-desert ecosystems in the 1980s than we understood in 1934.

Predation by coyotes has been a controversial problem on the western range, especially since many animal-control poisons were banned. In a recent study in Nevada, losses from predation were scientifically documented during a year-long cycle involving one sheep herd. Although predation was the popular controversy of the time, in this study losses of sheep from halogeton equaled losses to predators (Donald Klebenow, personal communication, 1980). Lynn James agrees that most years, sheep losses to halogeton probably exceed losses to predators on the range.

[1] In reviewing this manuscript, Dr. Lynn James, poisonous plant researcher, with USDA's Agricultural Research Service, questioned the specifics of the Garrison disaster, concluding that virtually every large loss of sheep to halogeton was the result of poor management.

Chapter 13. The Significance of Halogeton

Halogeton is a small genus in a large tribe of the family Chenopodiaceae. As it evolved in central Asia, this tribe apparently was subject to selection pressures that resulted in the evolution of many genera, some of which (for example, *Salsola*) contain numerous species. Growing naturally among this array of related plant material, *Halogeton glomeratus* adapted to transitory environments at the margins of playas where soluble salts in the soil are in balance with available soil moisture, conditions that limited the growth of most other chenopods. From our limited knowledge of the plant-community ecology of central Asia (see Walter and Box 1953) halogeton is merely a small cog in an intricate array of interacting plant assemblages. In evolving to exist in a relatively insignificant ecological niche, halogeton became equipped, through natural selection, with some remarkable attributes.

Among these attributes are

- the inherent ability to absorb relatively large quantities of normally toxic ions in order to maintain osmotic equilibrium.

- polymorphic seed production, controlled by photoperiodism, to ensure simultaneous and continuous germination. The metabolic process of shunting aside phytotoxic ions, which enter halogeton plants in salty water solutions, has two side effects with profound consequences: (1) through the formulation of oxalates, the herbage is rendered toxic, and (2) the residue left when the plants die and decay increases the salt content of surfaces, rendering them toxic to the germination of many potentially competing species.

Despite apparently having been selected for a relative specific environment, halogeton did quite well when introduced to a similar macroenvironment in North America. This suggests the interaction of three factors:

- Halogeton enjoyed the obvious competitive advantage of being an alien. It was introduced without its complement of co-evolved pests—microbial and higher plants and animals.

- Halogeton was introduced into an environment where herbaceous vegetation had been virtually destroyed by excessive, improperly timed grazing of domestic animals.

- The Intermountain Area had not produced highly competitive annuals to occupy transitory habitat.

In exploiting this biological near-vacuum, how has *H. glomeratus* changed from the apparent limited genetic variability of the original introduction? What breeding system has the species employed to advantageously exploit 11.25 million acres in four decades? Not only have these questions not been explained, apparently they have not been asked.

Halogeton interacted with the regeneration ecology of the perennial half-shrubs in the Intermountain Area—*Kochia americana, Ceratoides lanata,* and *Atriplex nuttallii.* These three shrubs were preferred browse species, tended to form monospecific communities, and were often severely overgrazed. J.H. Robertson, L.A. Stoddart, and Lee Sharp saw the significance of this environmental overlap of halogeton and the three shrubs and directed their students and colleagues to study competition among these shrubs and evaluate the nature of the environments where the competition occurred.

Understanding the regeneration ecology of these three species was, and still is, the key to halogeton suppression in salt-desert environments. Sharp recognized this when he tried to obtain support for the Salt Desert Shrub Range Revegetation Committee. The attempted substitution of the exotic *Kochia prostrata* for the three native species did not solve the basic problem of regeneration ecology.

On *Artemisia* rangeland, the adaptation of the exotic crested wheatgrass was a stroke of luck for the environment. That notwithstanding, crested wheatgrass became a highly controversial species as the age of environmentalism swept the western range. Its seedings became the symbol of single-use management of natural resources, as wildlife managers blamed it for declines in the variety of species. Many people preferred the natural look of degraded sagebrush communities to the rectangular stands of grass arranged in rows.

Perhaps a more valid concept of crested wheatgrass is that of a biological holding action. Crested wheatgrass was inserted into a severely degraded environment, and it went a long way toward stabilizing that environment and the livestock industry that depended on the grazing resources. It is interesting to consider how permanent crested wheatgrass is among the various habitat types found in the Great Basin.

Politically, the selling to Congress of the principle that federal monies should be used to rehabilitate degraded public rangelands was a milestone in environmental conservation. These monies were appropriated to treat halogeton invasion, a mere symptom of the underlying malady of environmental degradation.

Those who sold this program—L.A. Stoddart, J.H. Robertson, Lee Sharp, and Marian Clawson—were the heroes of the halogeton episode in western range management.

Special credit is due L.M. Burge who persisted, in spite of his philosophical opposition and obtained the political support necessary to pass the halogeton bill. While never funded, the bill prompted the funding of seeding programs by the Bureau of Land Management and research by the U.S. Department of Agriculture.

The failure to control halogeton through biological means needs analysis. First, halogeton belongs to a large family that contains economically valuable species. A major economic species, sugar beets evolved in the same general environment as halogeton and are cultured in the same general environment in North America. Halogeton and sugar beets exchange insect pests. Halogeton is an annual whose population sizes are highly variable from year to year depending on soil moisture. A specific pest would have to evolve with this high-risk host. Entomologists searching for biological control organisms could have profited from cooperation with plant geographers, taxonomists, physiologists, and ecologists. Politically, the problems of studying and collecting in Russian central Asia made the biological control program extremely difficult to undertake. The Russian space program is based in the center of that halogeton habitat.

Is biological control of halogeton desirable? On the surface, this seems to be a ridiculous question, but in specific communities what would replace halogeton? In the Great Basin much of the habitat formerly enjoyed by halogeton is now being occupied by a new competitor, barbwire Russian thistle.

The major accomplishment of herbicidal control of halogeton has been the widespread use of soil-active herbicides for roadside weed control. The ecological significance of these programs and their influence on the composition and dispersal of ruderal species in the great Basin have not been touched by experimental research.

Huge advances have been made in physiological and pathological sheep studies of oxalate poisoning. Translating this knowledge into management practices is the key to living with halogeton.

Historically, halogeton accelerated the demise of a declining industry. The range sheep industry, as it evolved in the Intermountain Area during the first half of the 20th century, was in decline before halogeton became a problem.

If another alien, poisonous plant were suddenly found to be rapidly spreading on the sagebrush and salt-desert ranges of the Intermountain Area, what would be the reaction of regulator agencies—kill, suppress, or ignore? Perennial pepperweed or tall whitetop (*Lepidium latifolium* L.) has rapidly spread in riparian habitats in the Great Basin during the past decade. There are rumors that it is poisonous. Where did it come from? How far will it spread? What is the correct scientific name for this plant? These questions sound all too familiar.

Having reached an environmental equilibrium in the Great Basin, halogeton is actually on the decline. Much of this decline can be attributed to improved range conditions but the genetic and biological reasons still need to be investigated.

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